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(45) **Date of Patent:** Jan. 29, 2019

(52) **U.S. Cl.**  
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(2013.01); ***B23D 47/08*** (2013.01); ***B27G***  
***19/02*** (2013.01); ***G01R 31/343*** (2013.01)

(58) **Field of Classification Search**  
CPC .... B23D 59/001; B23D 45/067; B23D 47/08;  
G01R 31/343; B27G 19/02; B27B 5/38;  
(Continued)

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 272 days.

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Primary Examiner — Anh V La

(65) **Prior Publication Data**

(74) *Attorney, Agent, or Firm* — Maginot Moore & Beck  
LLP

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(57) **ABSTRACT**

A method for measuring brush wear in a motor of a saw includes generating, with a sensor connected to a brush in a motor of the saw, a first signal corresponding to a level of wear in the brush and identifying, with a controller, a level of wear for the brush with reference to the first signal. The method further includes generating, with the controller and a user interface device, an output requesting replacement of the brush in response to the identified level of wear exceeding a predetermined threshold.

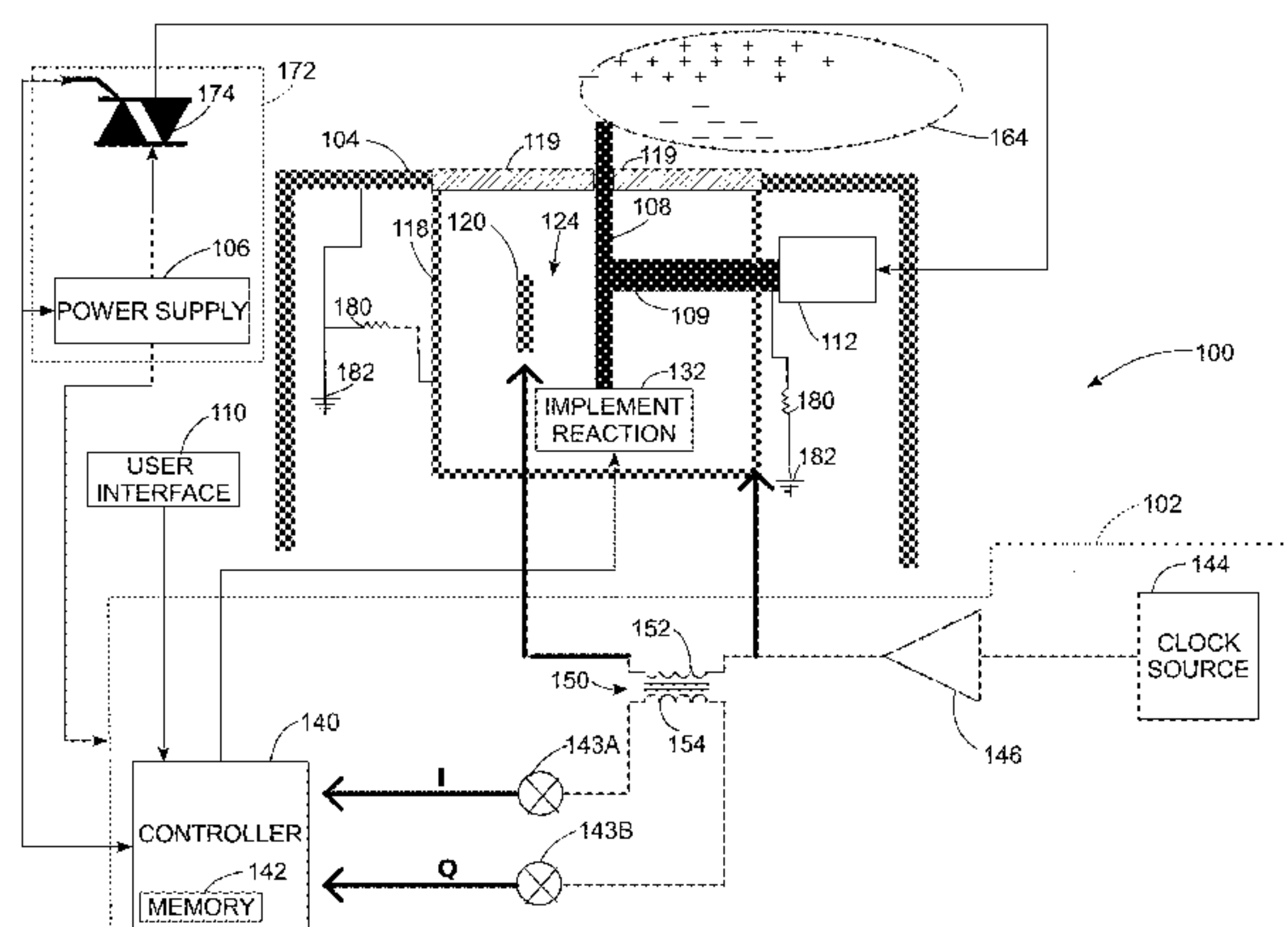
### Related U.S. Application Data

(60) Provisional application No. 62/131,977, filed on Mar. 12, 2015, provisional application No. 62/132,004, filed on Mar. 12, 2015.

(51) **Int. Cl.**  
**G08B 21/00** (2006.01)  
**B23D 59/00** (2006.01)

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**10 Claims, 21 Drawing Sheets**



\* cited by examiner



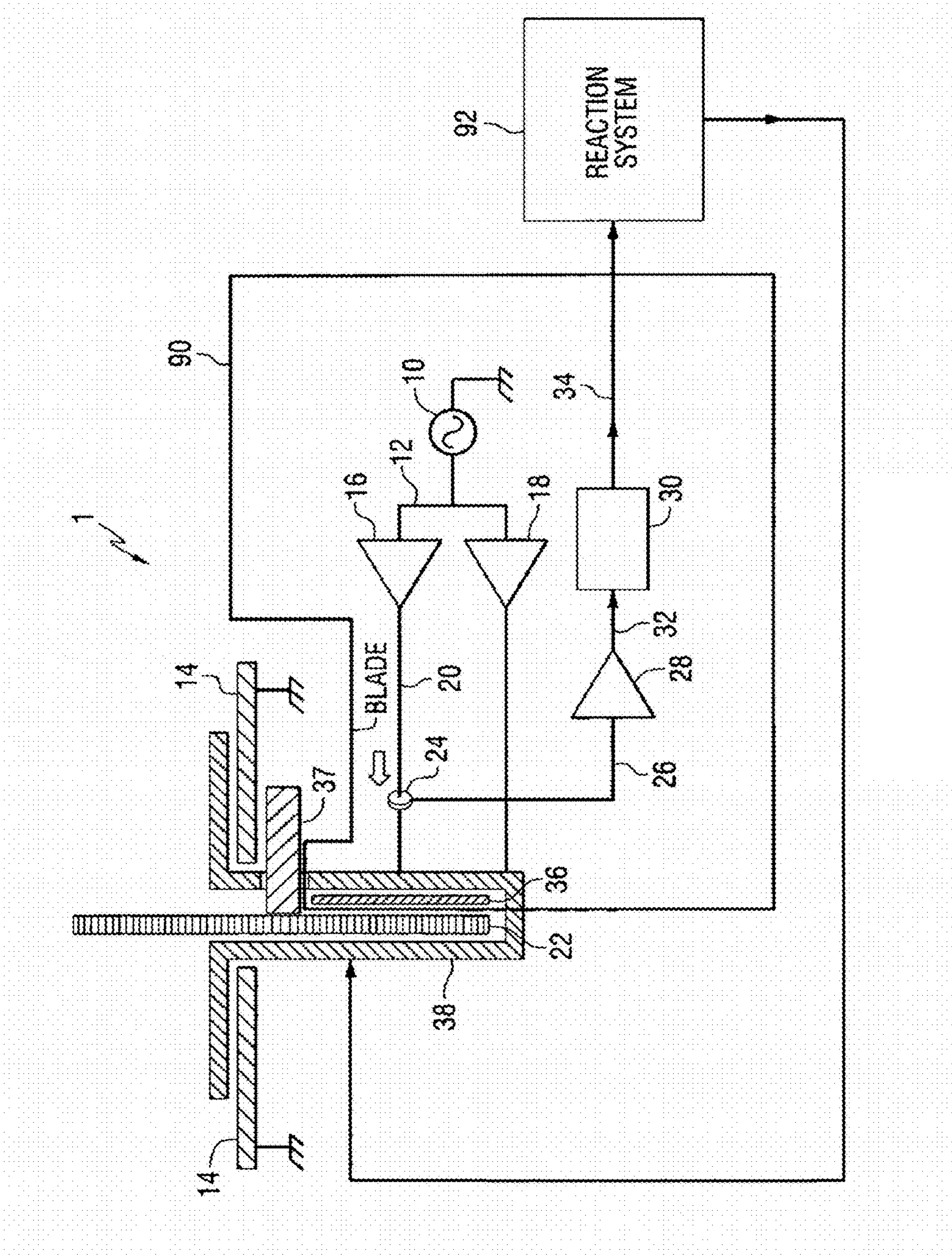


FIG.1  
PRIOR ART

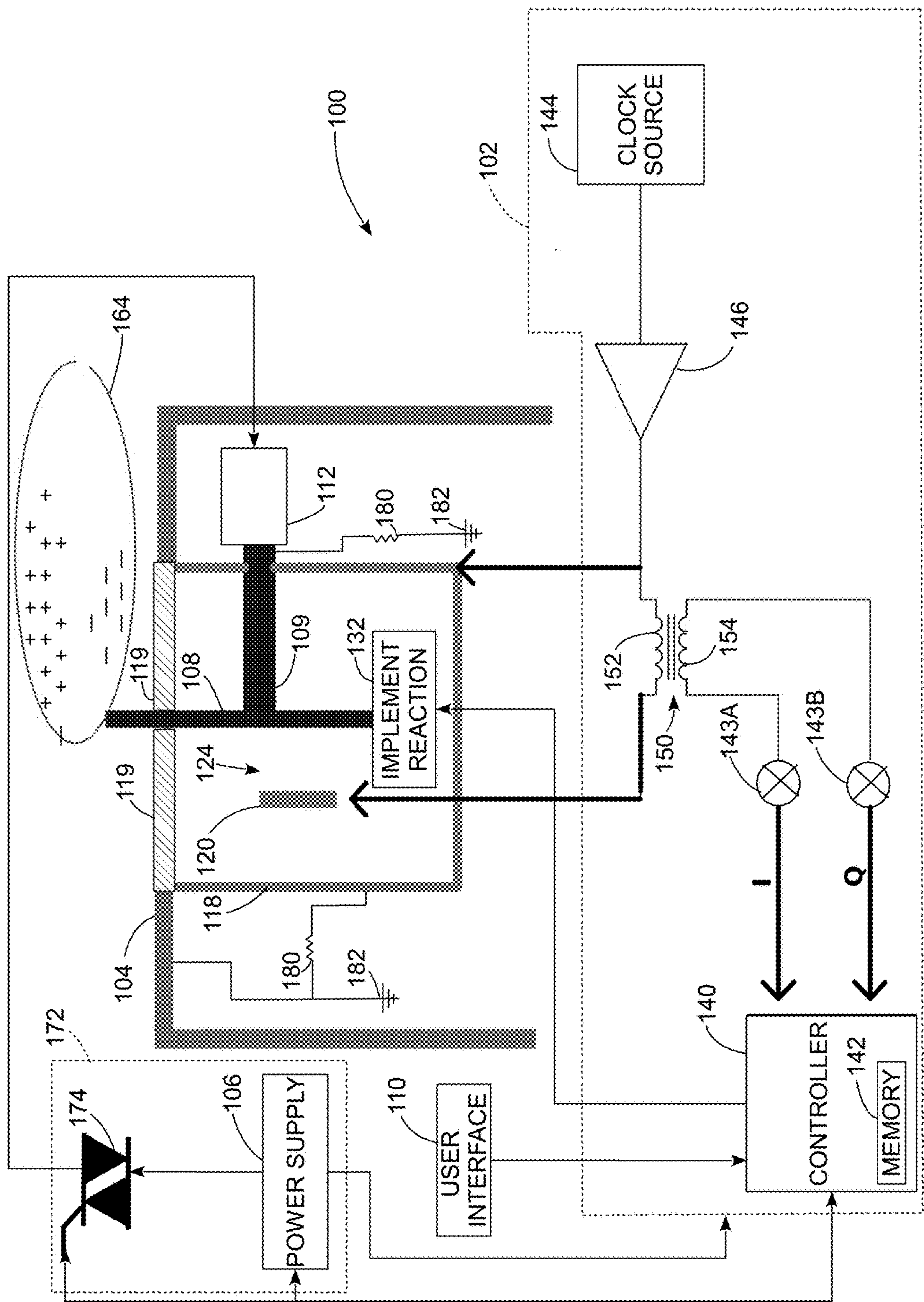


FIG. 2



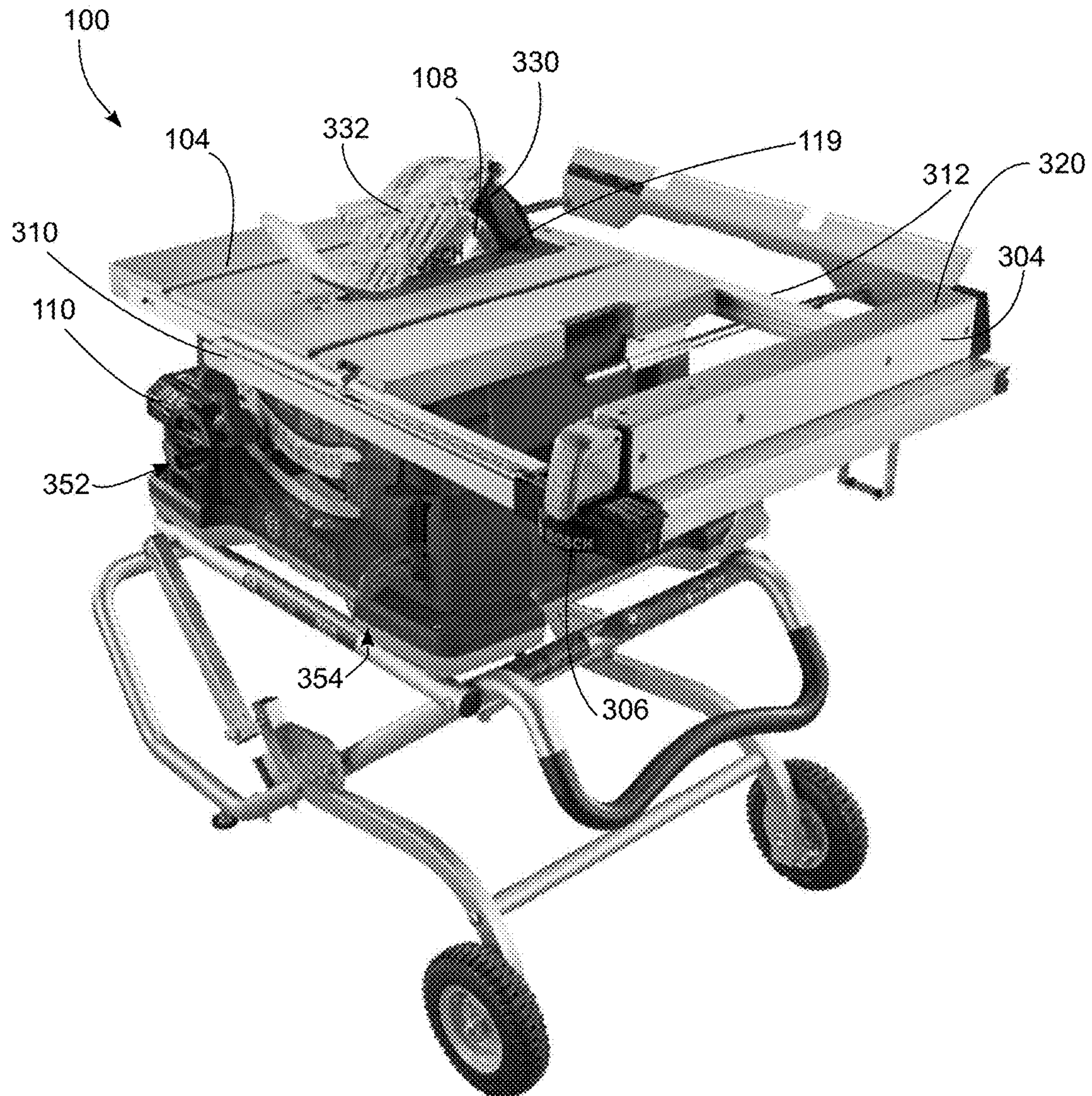


FIG. 3



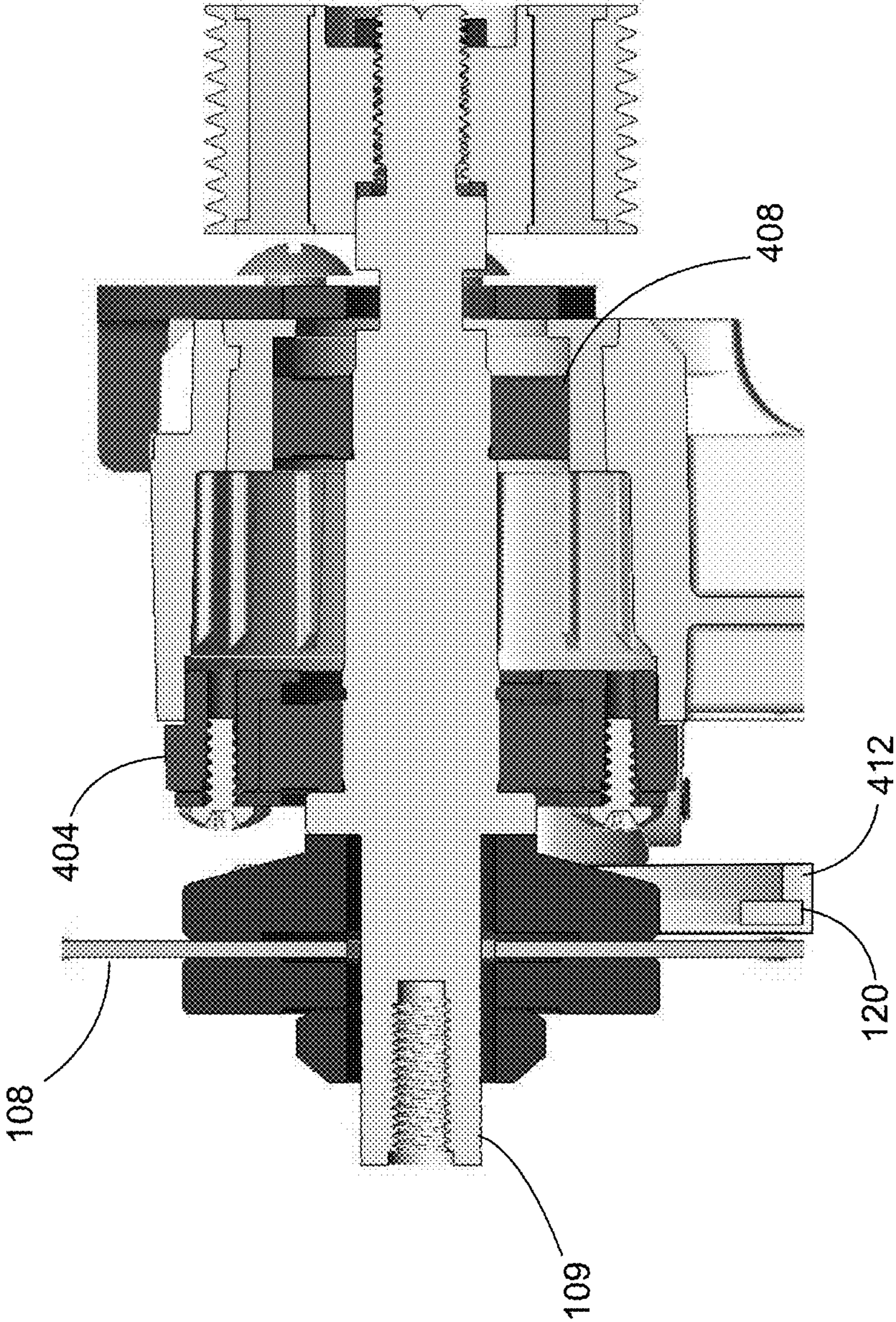


FIG. 4

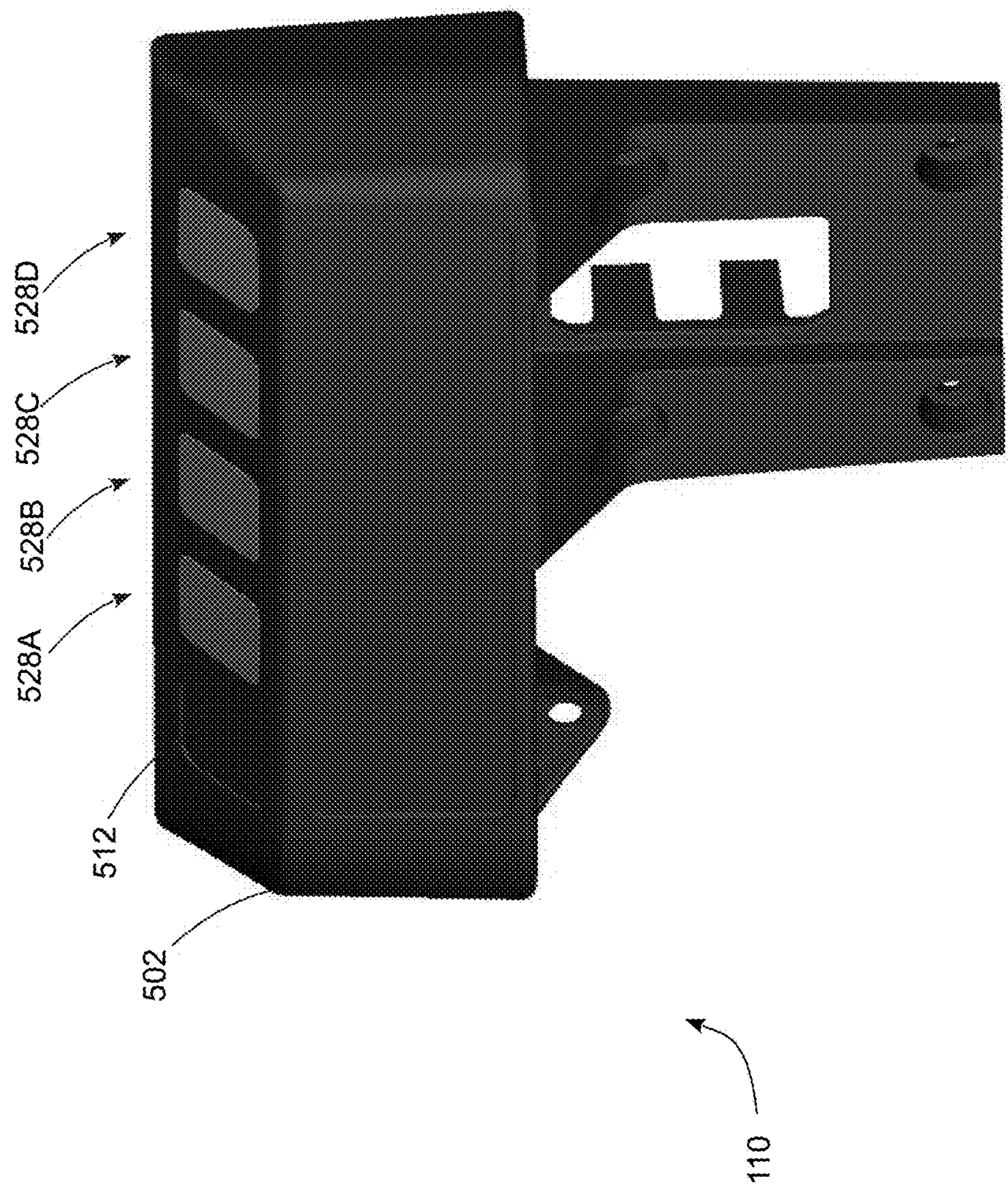


FIG. 5A



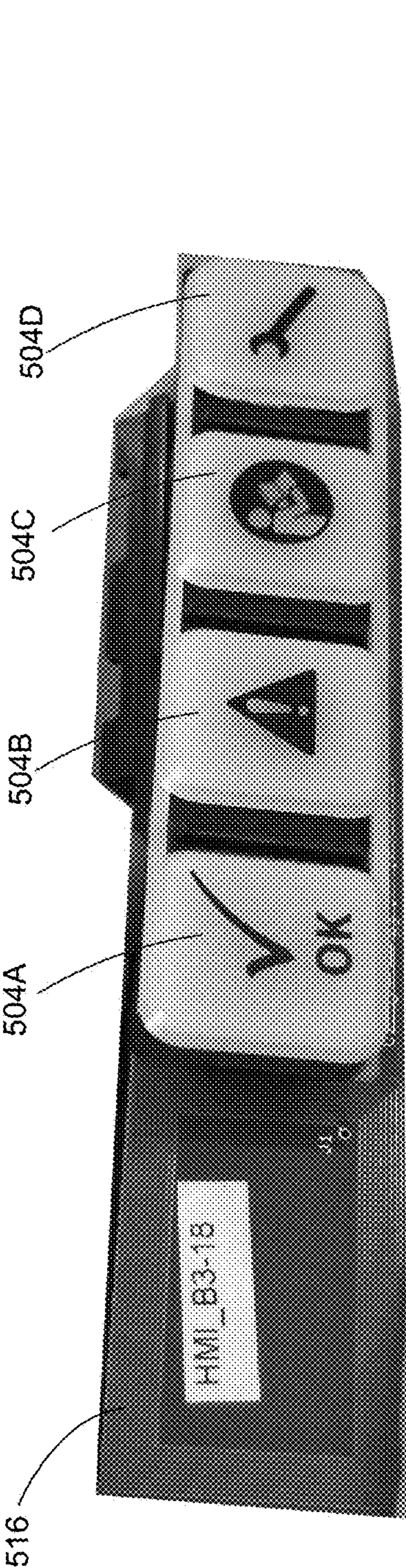


FIG. 5B

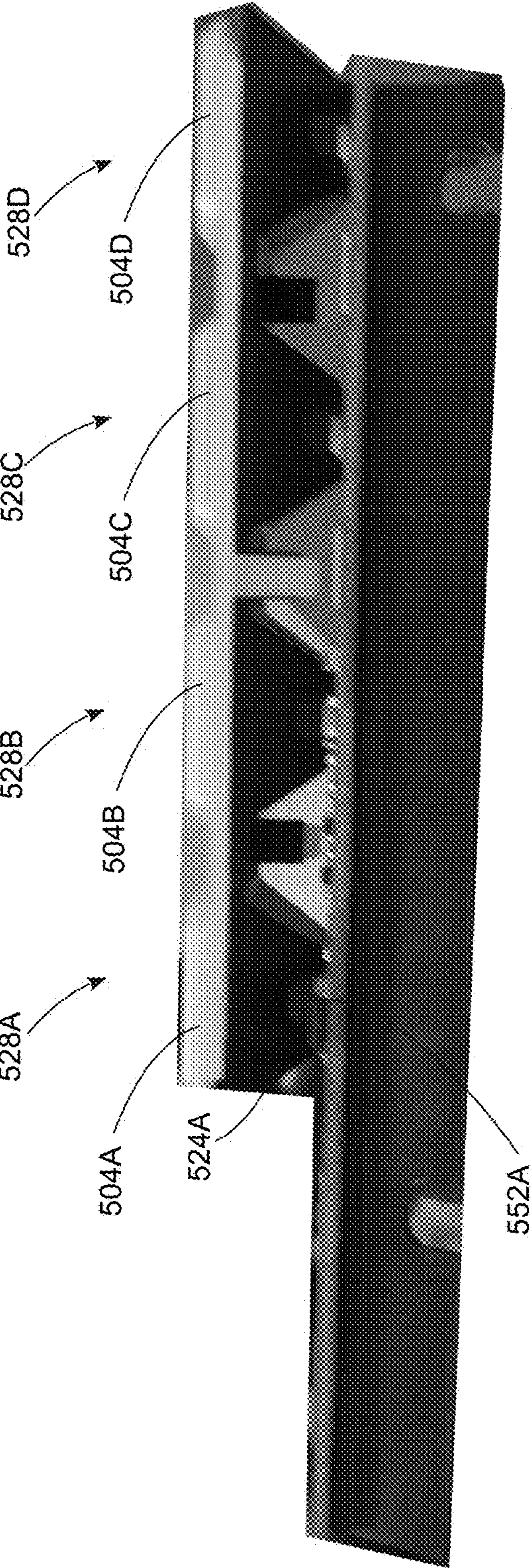


FIG. 5C



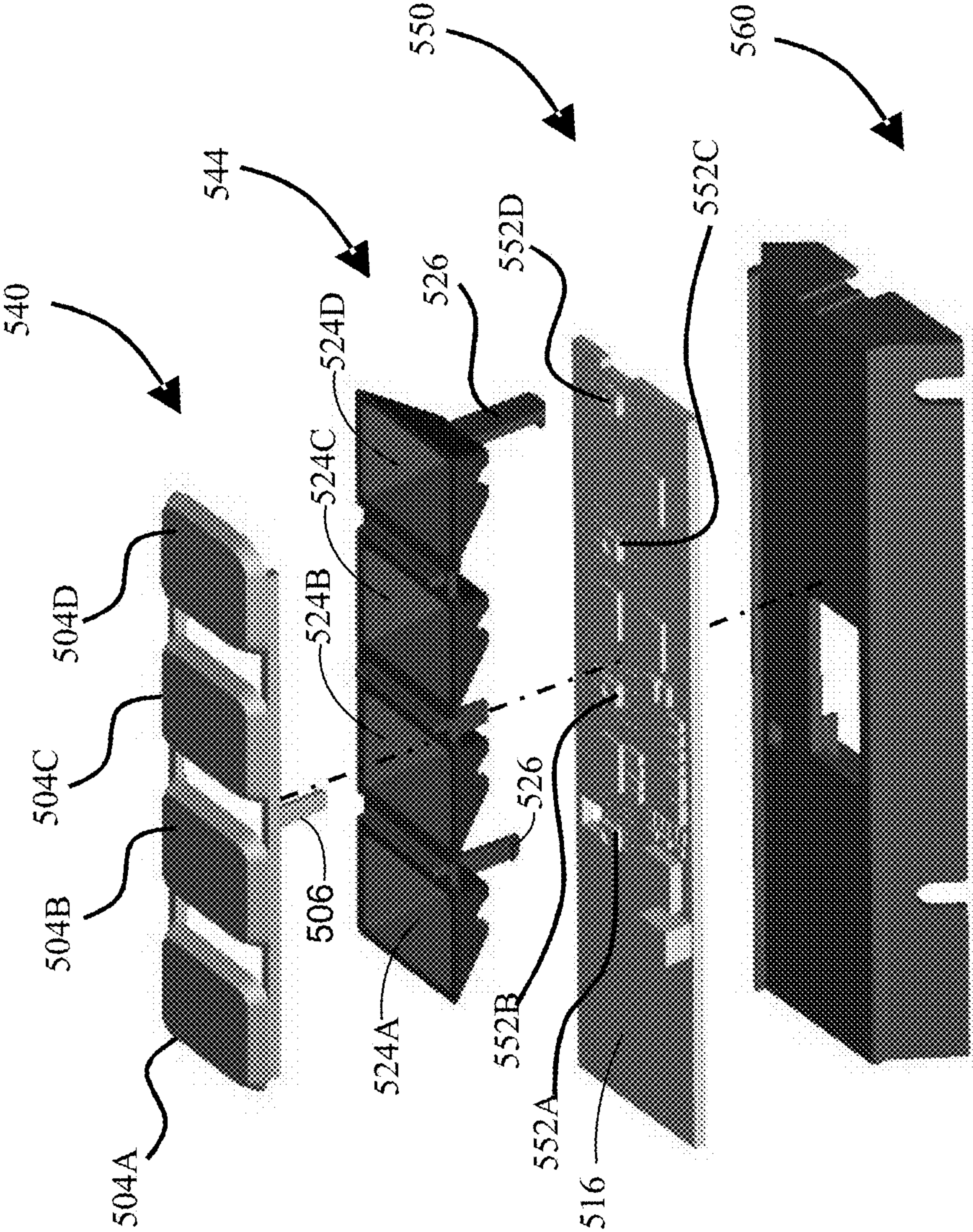


FIG. 5D



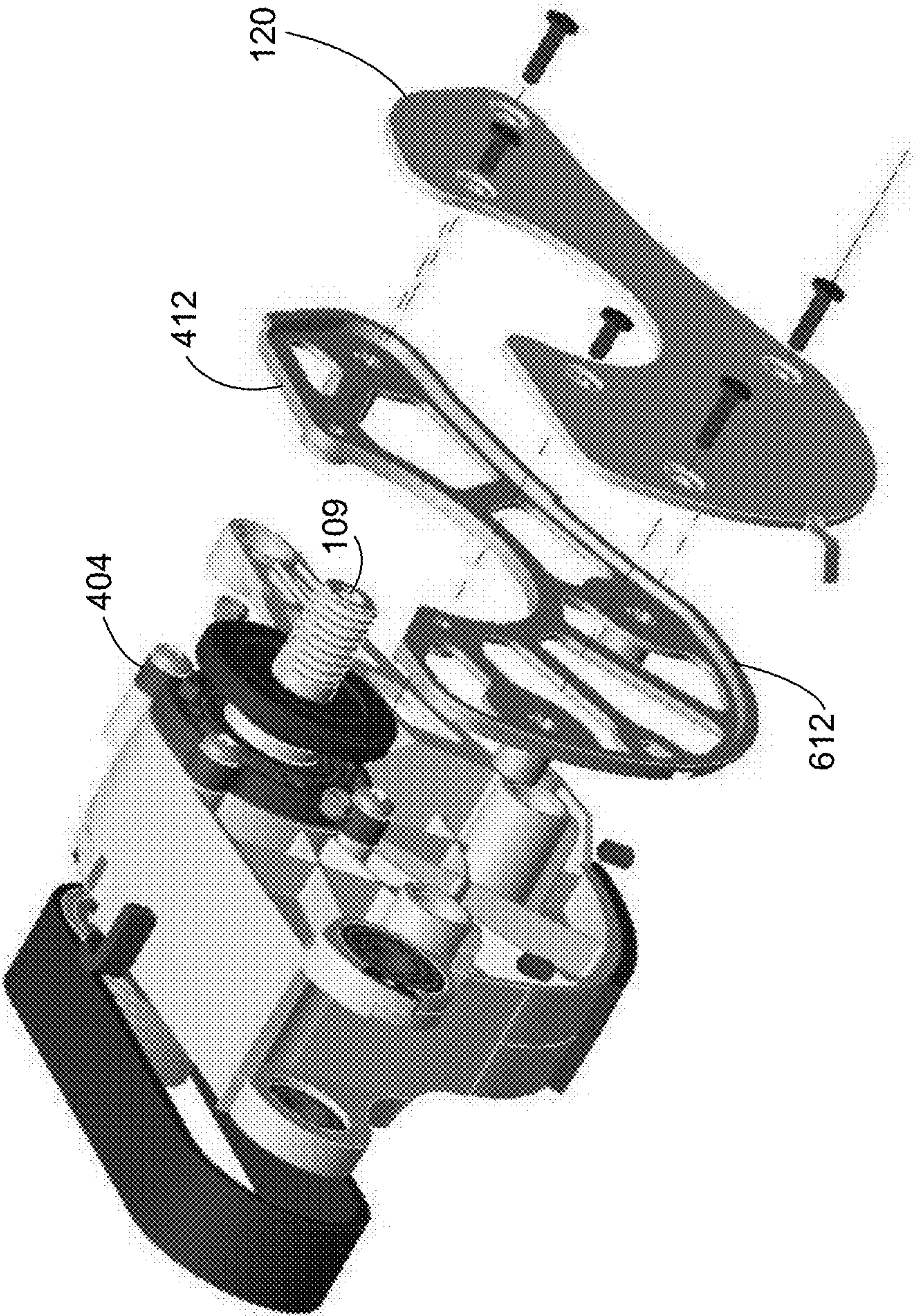


FIG. 6A



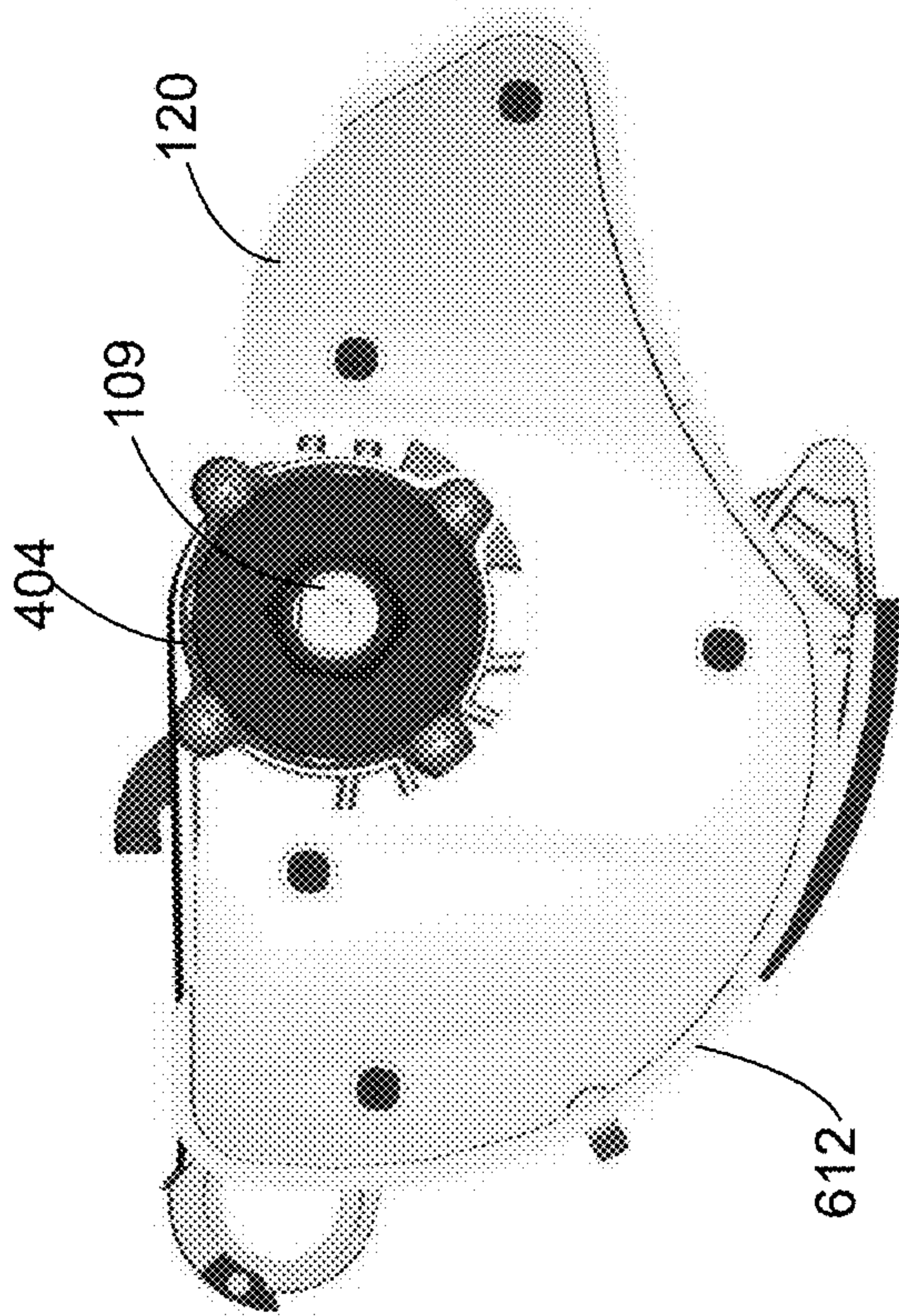


FIG. 6B

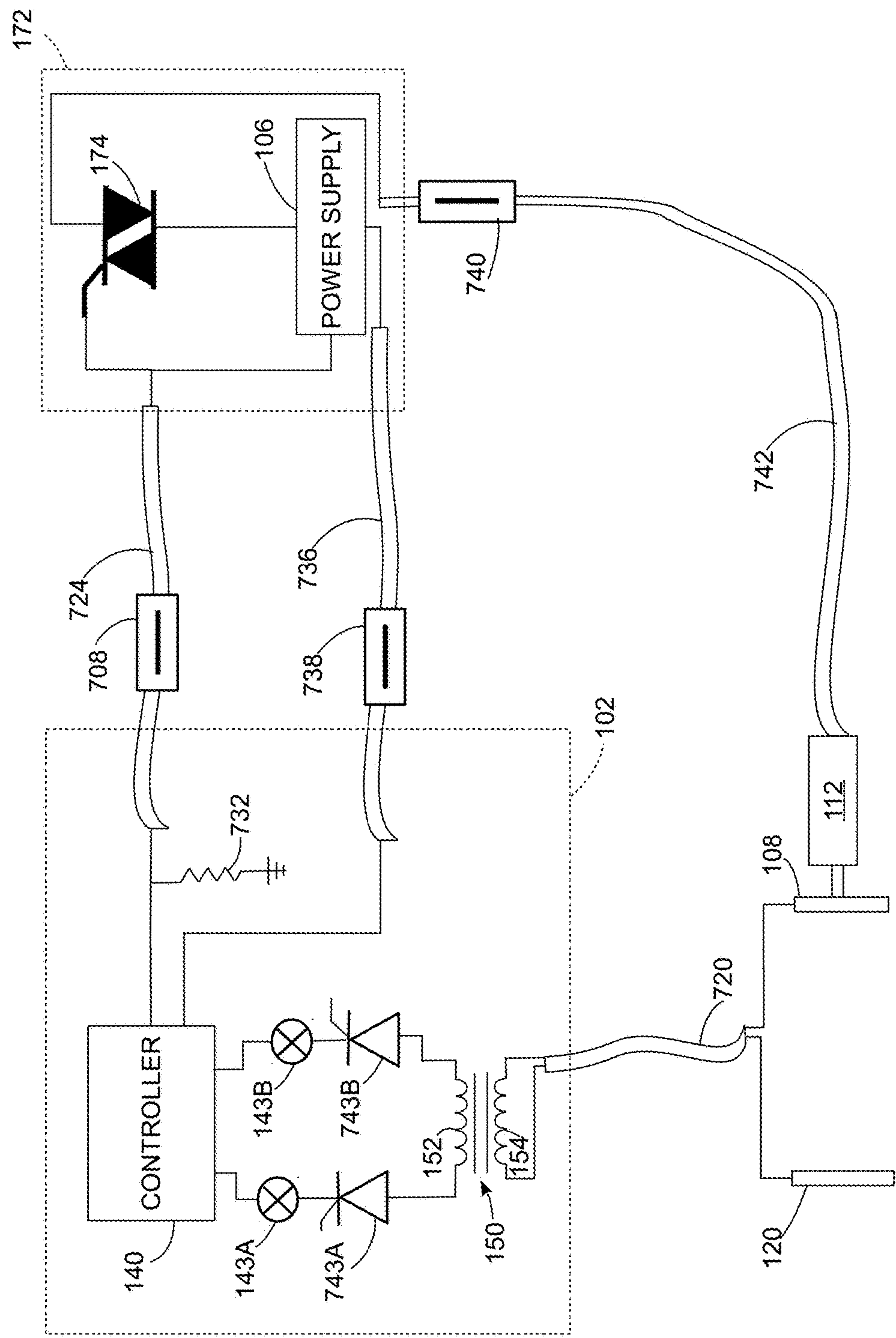


FIG. 7



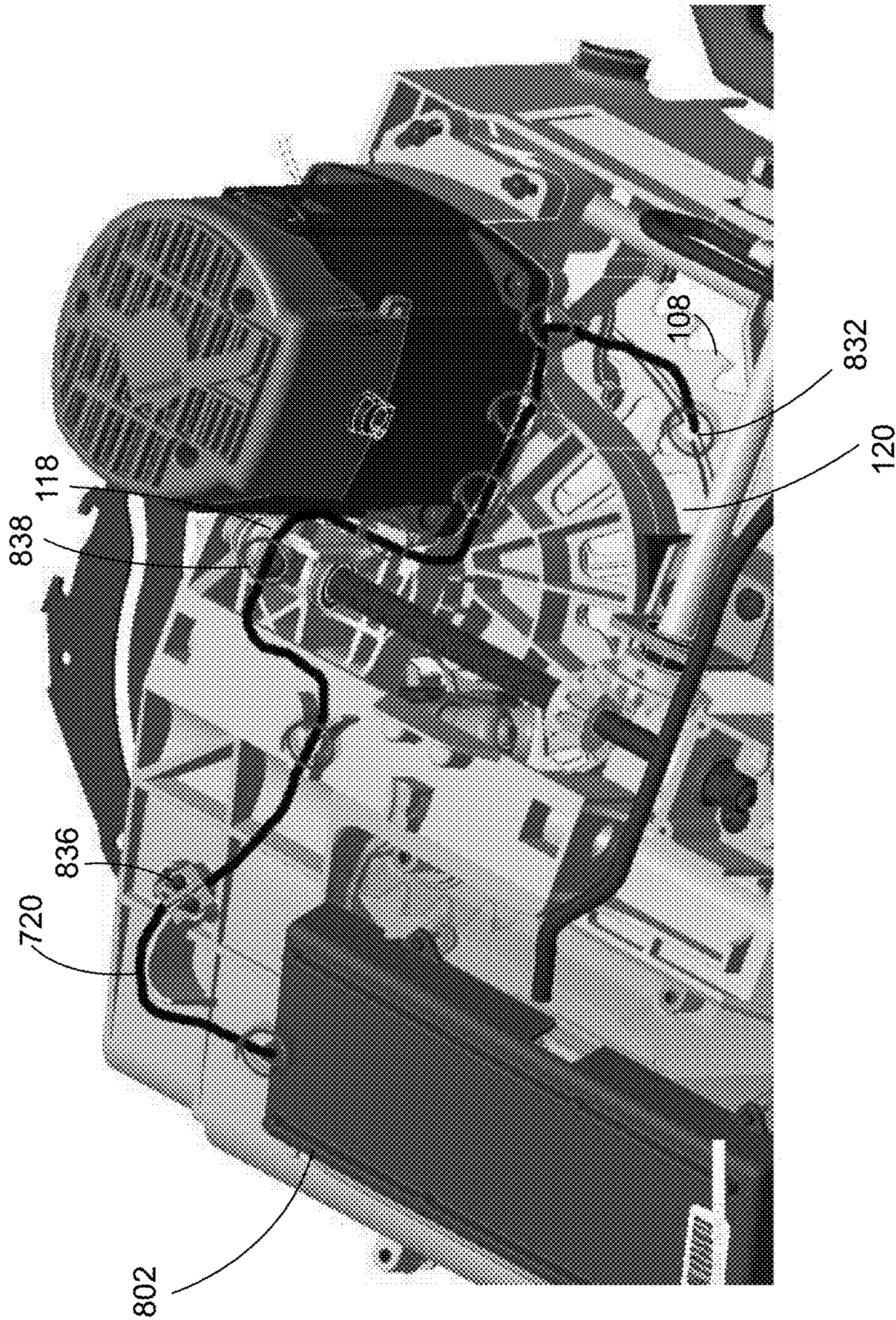


FIG. 8A



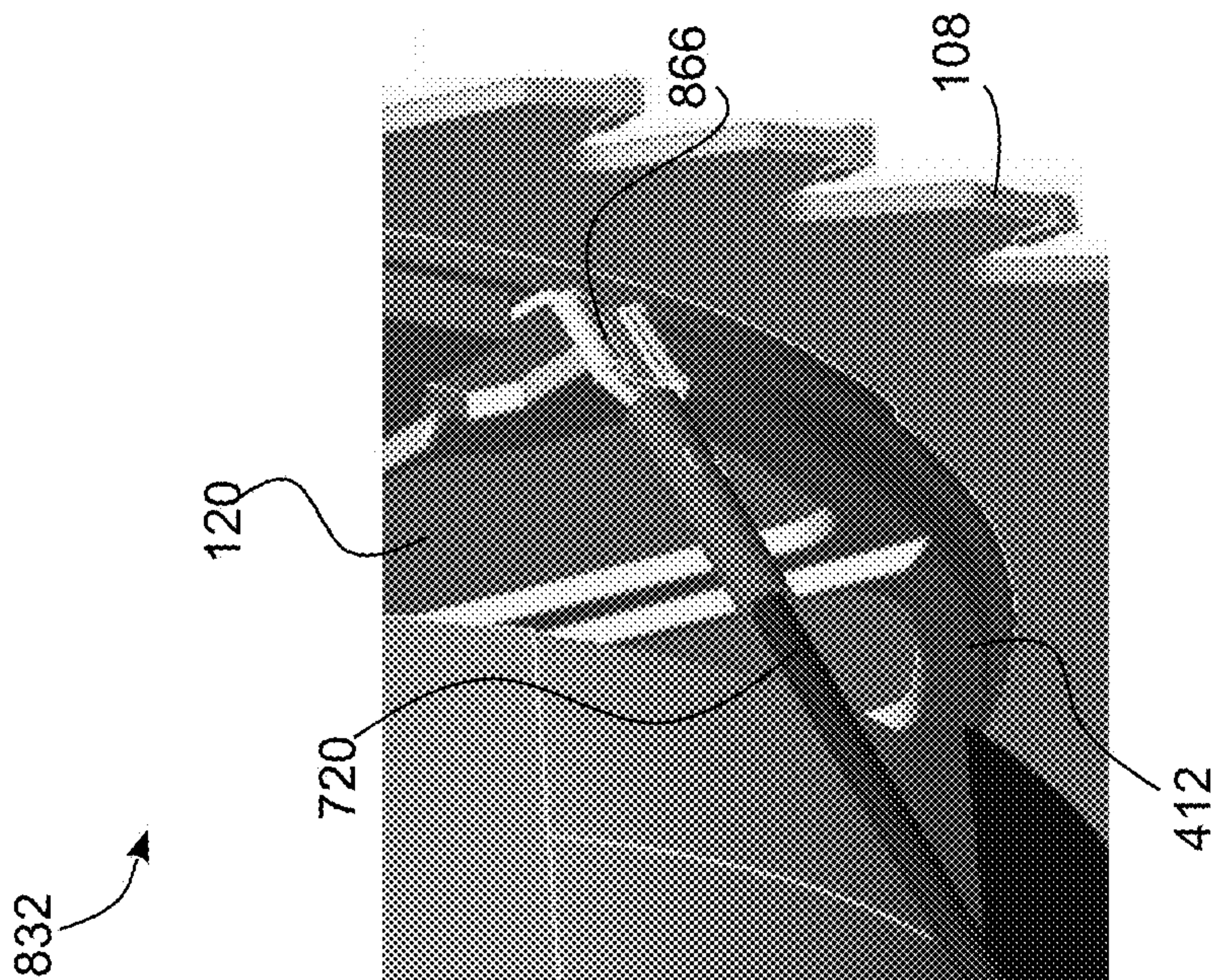


FIG. 8B

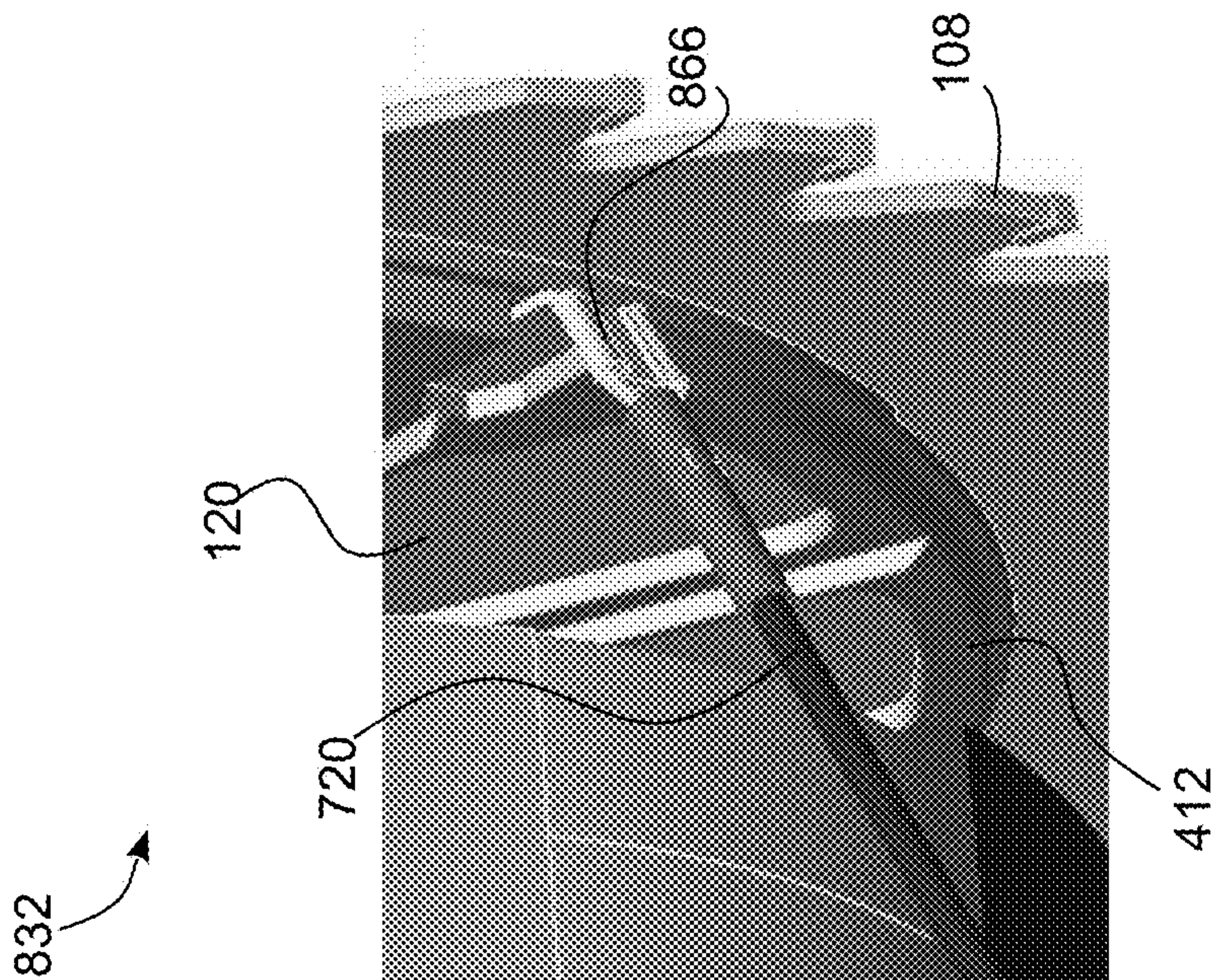


FIG. 8C



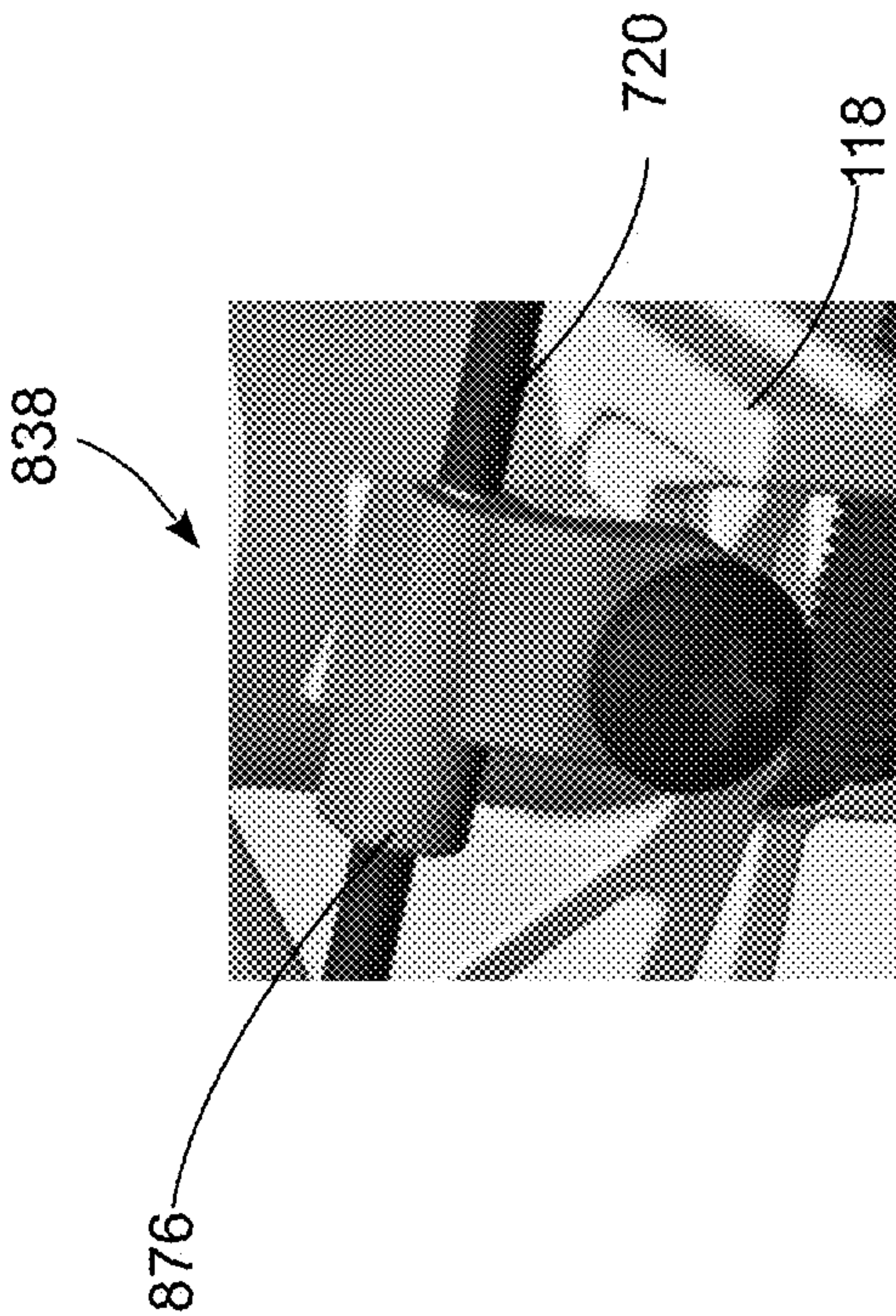


FIG. 8D

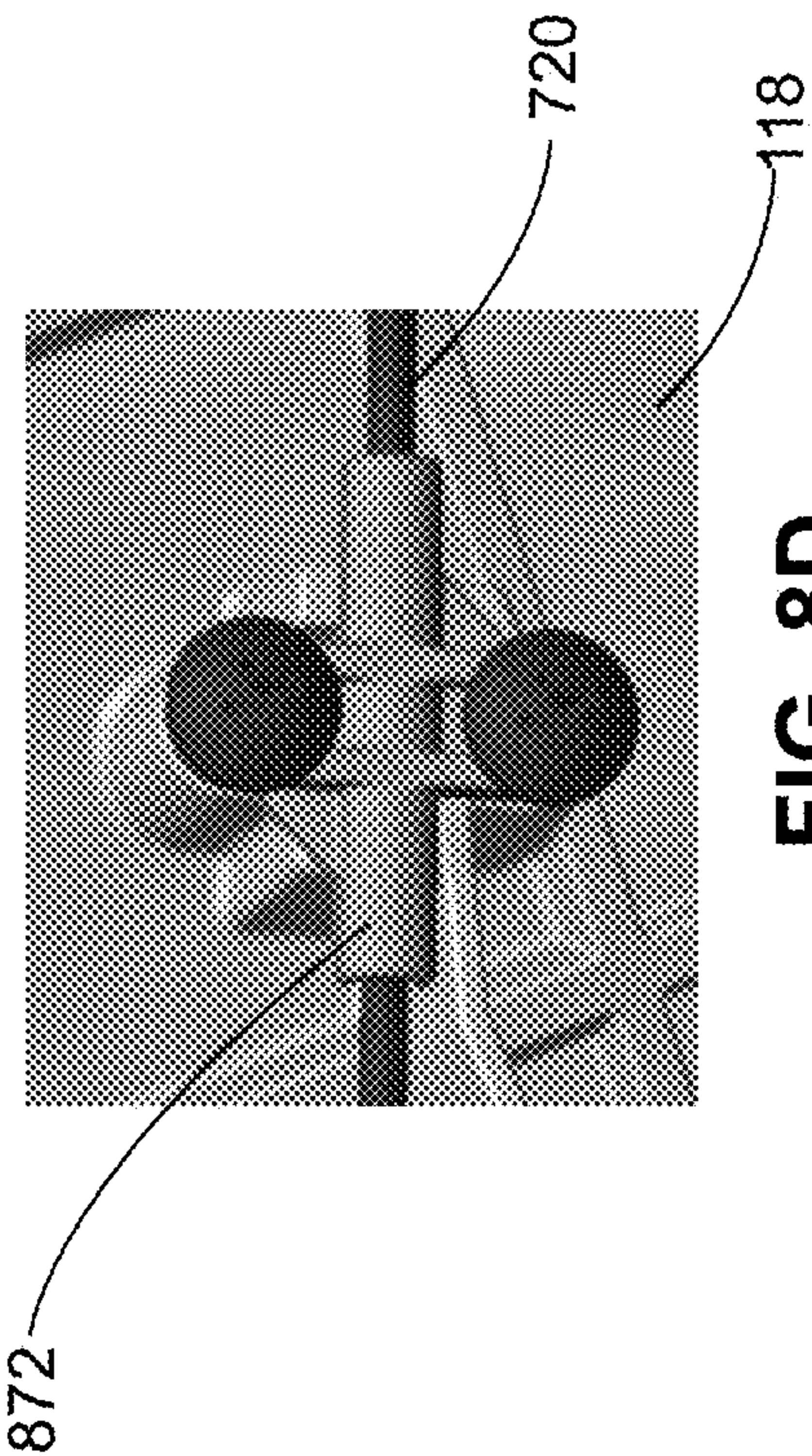


FIG. 8E

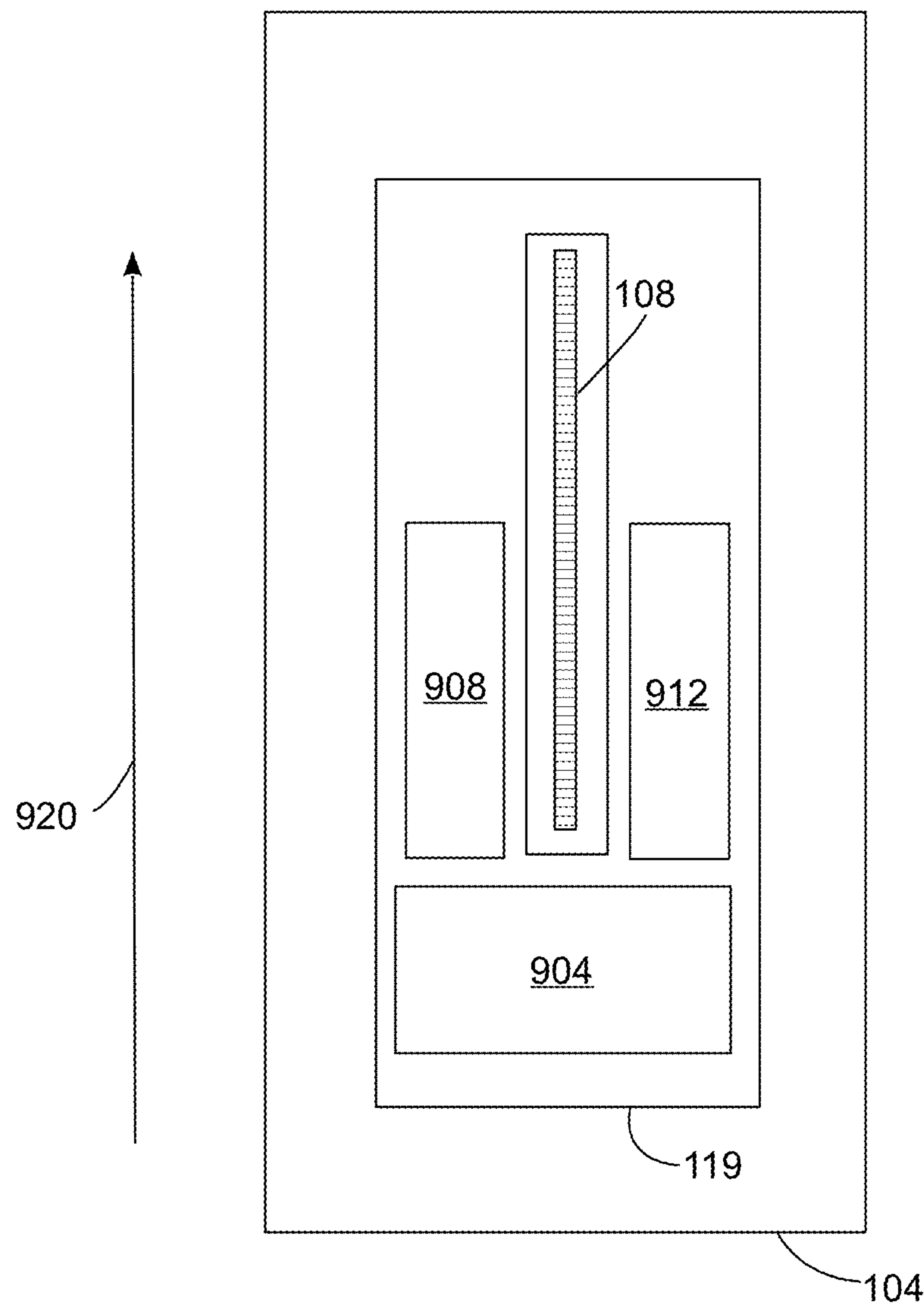


FIG. 9A



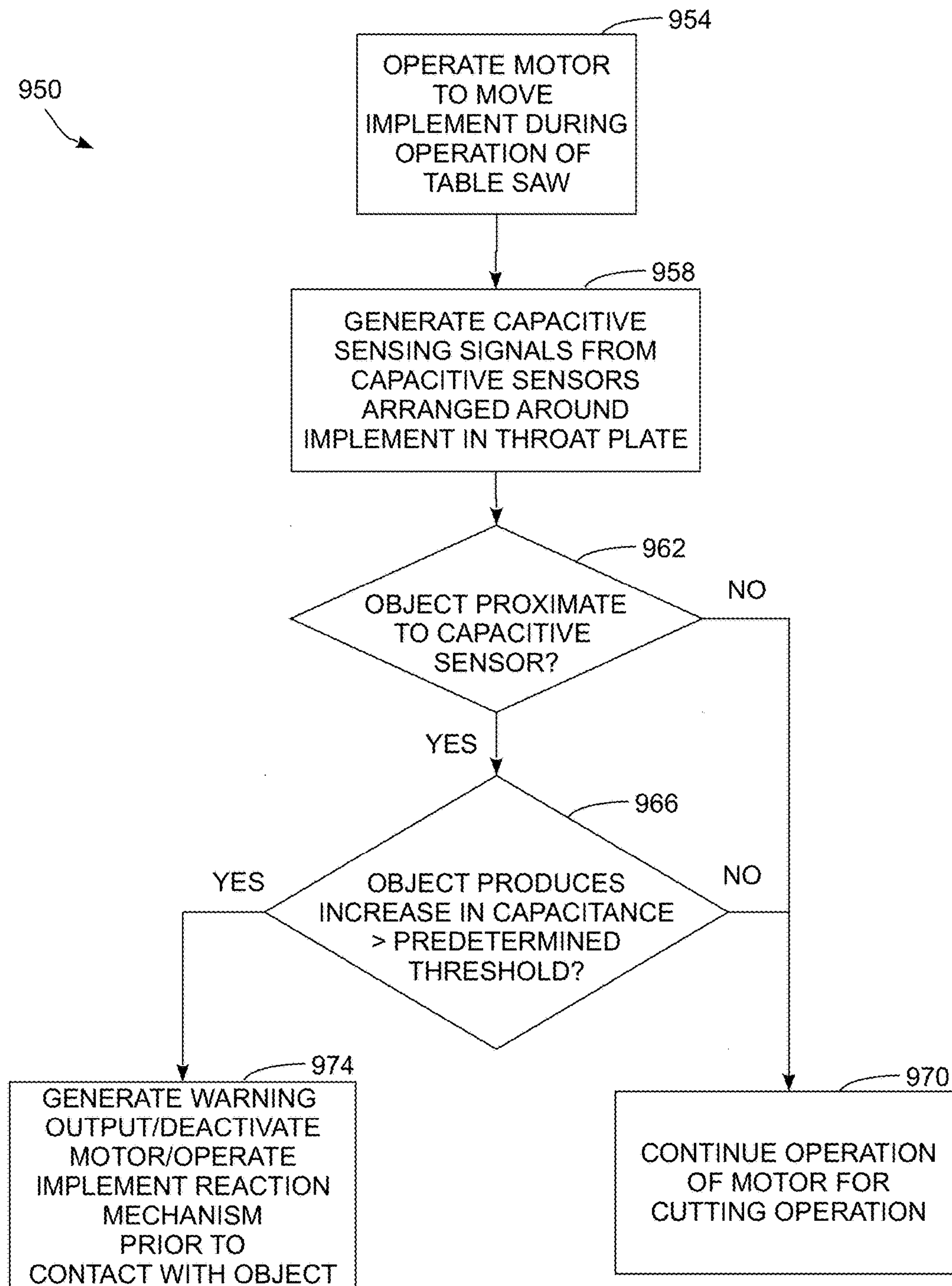


FIG. 9B



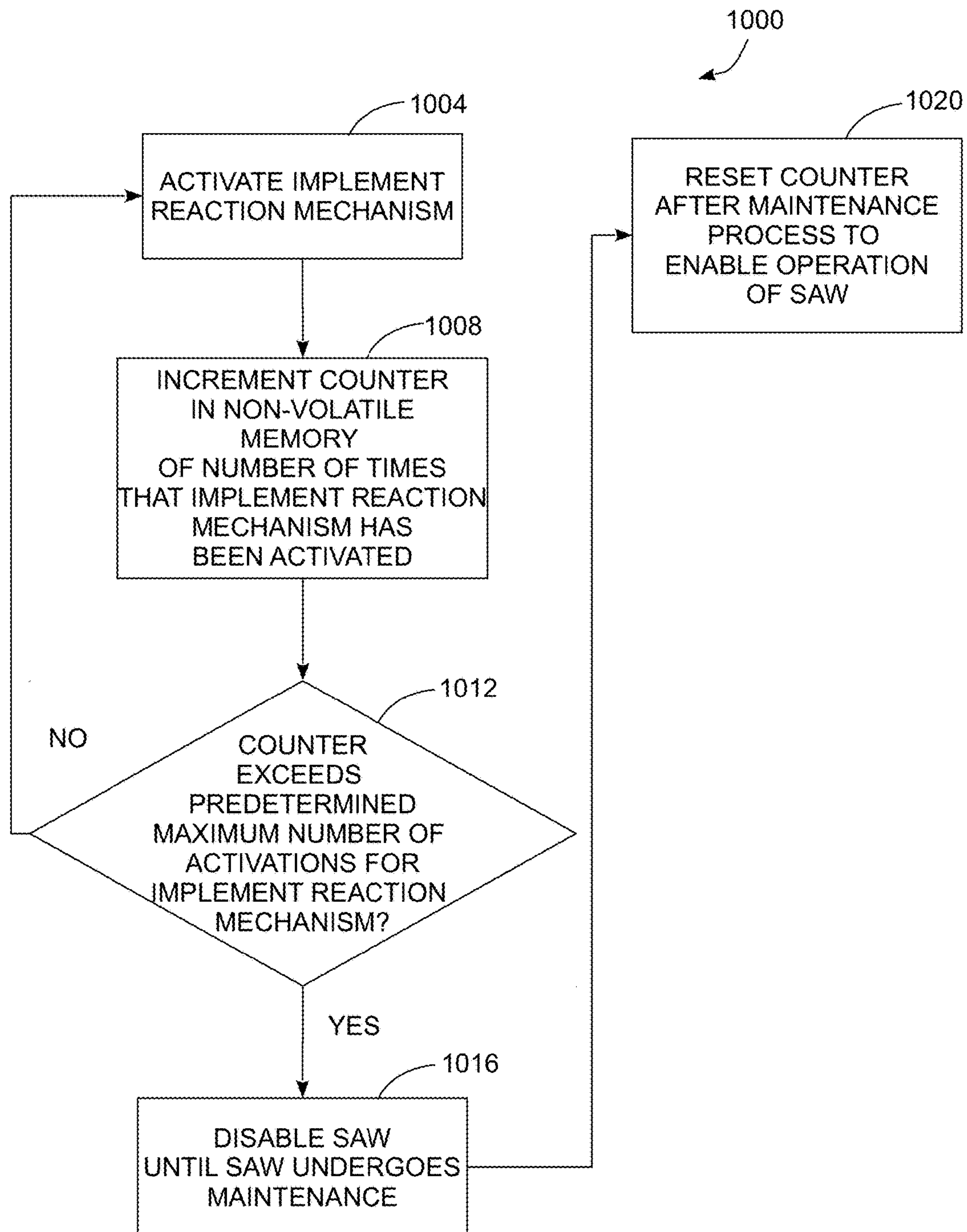


FIG. 10



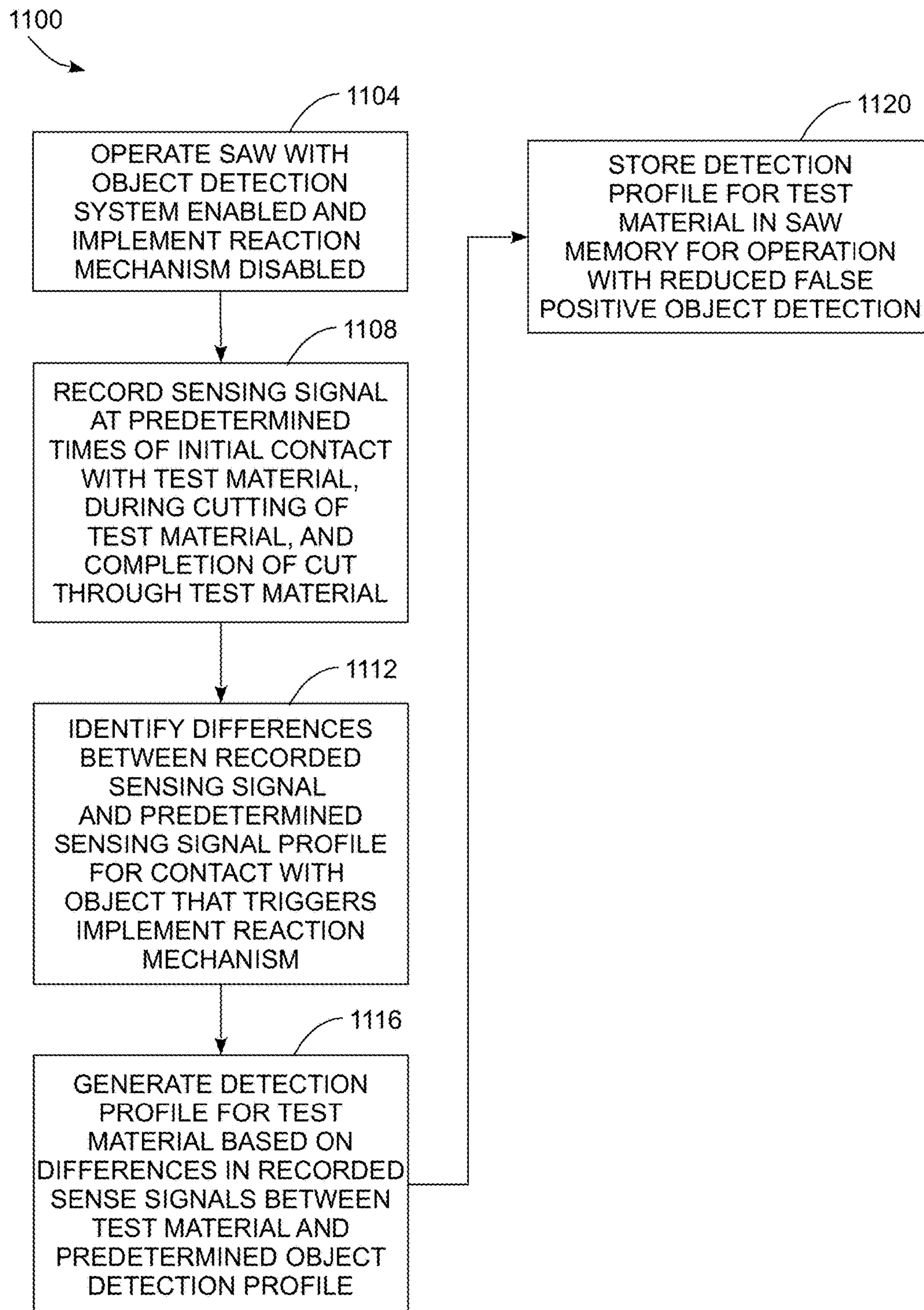
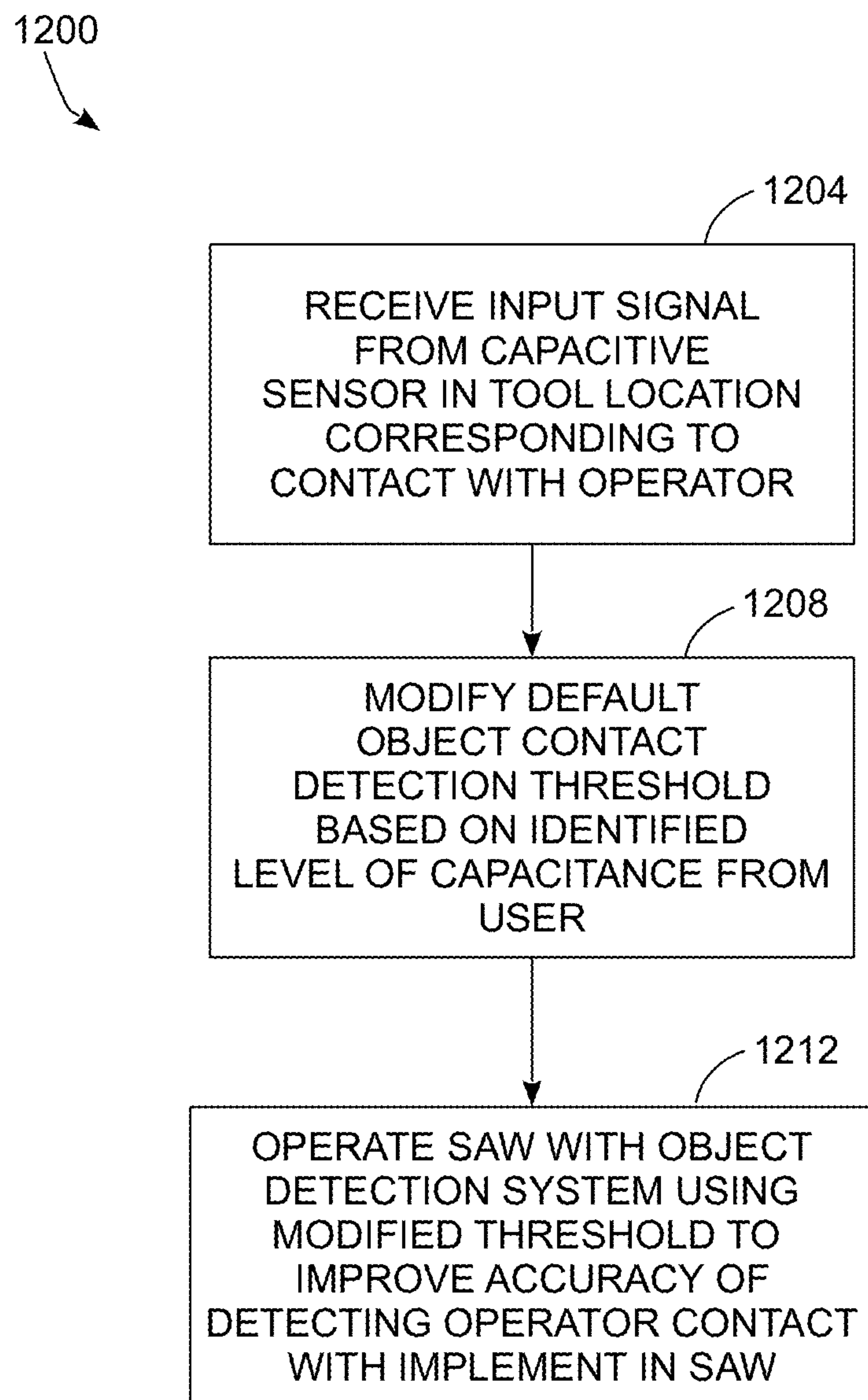
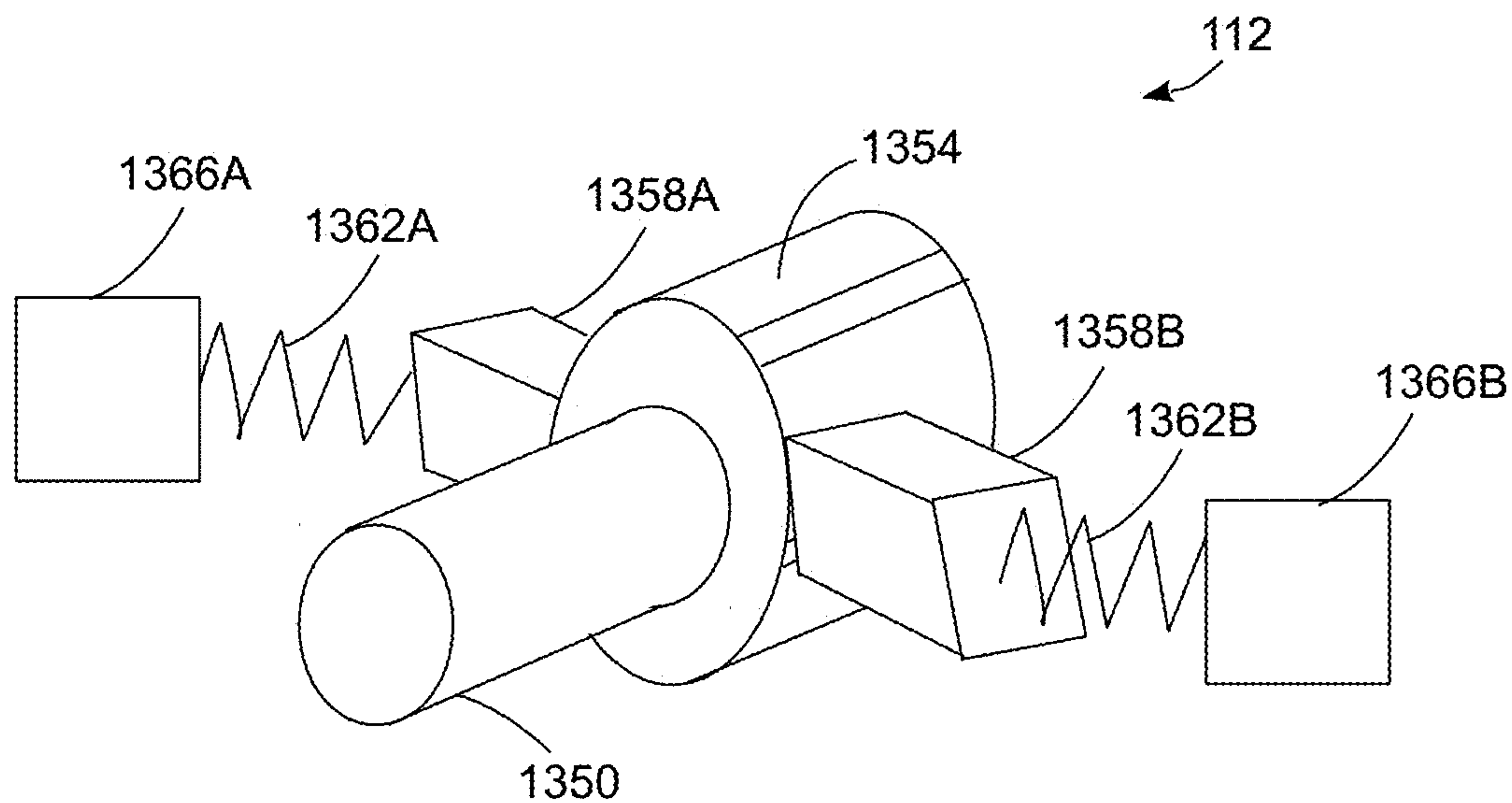
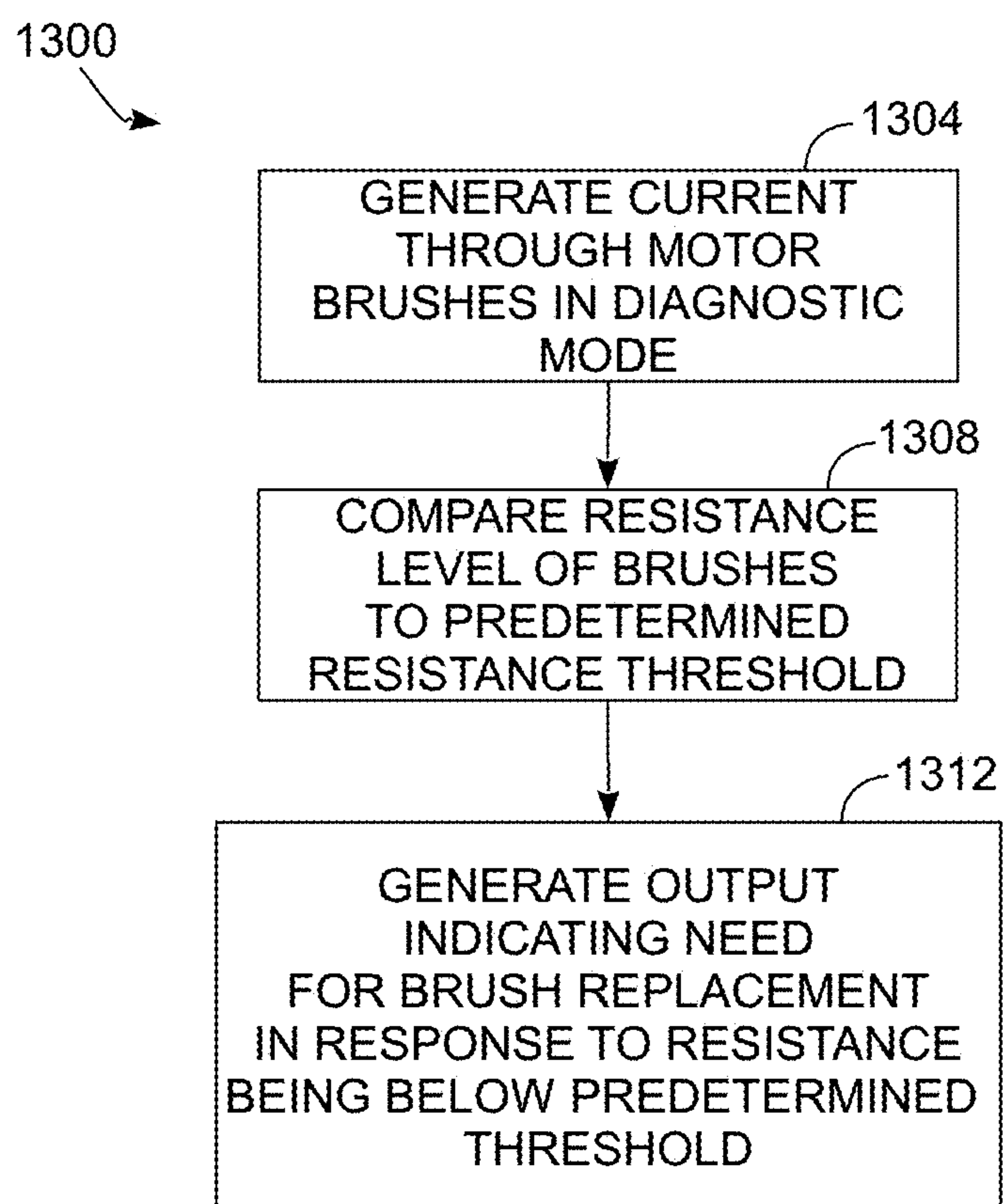
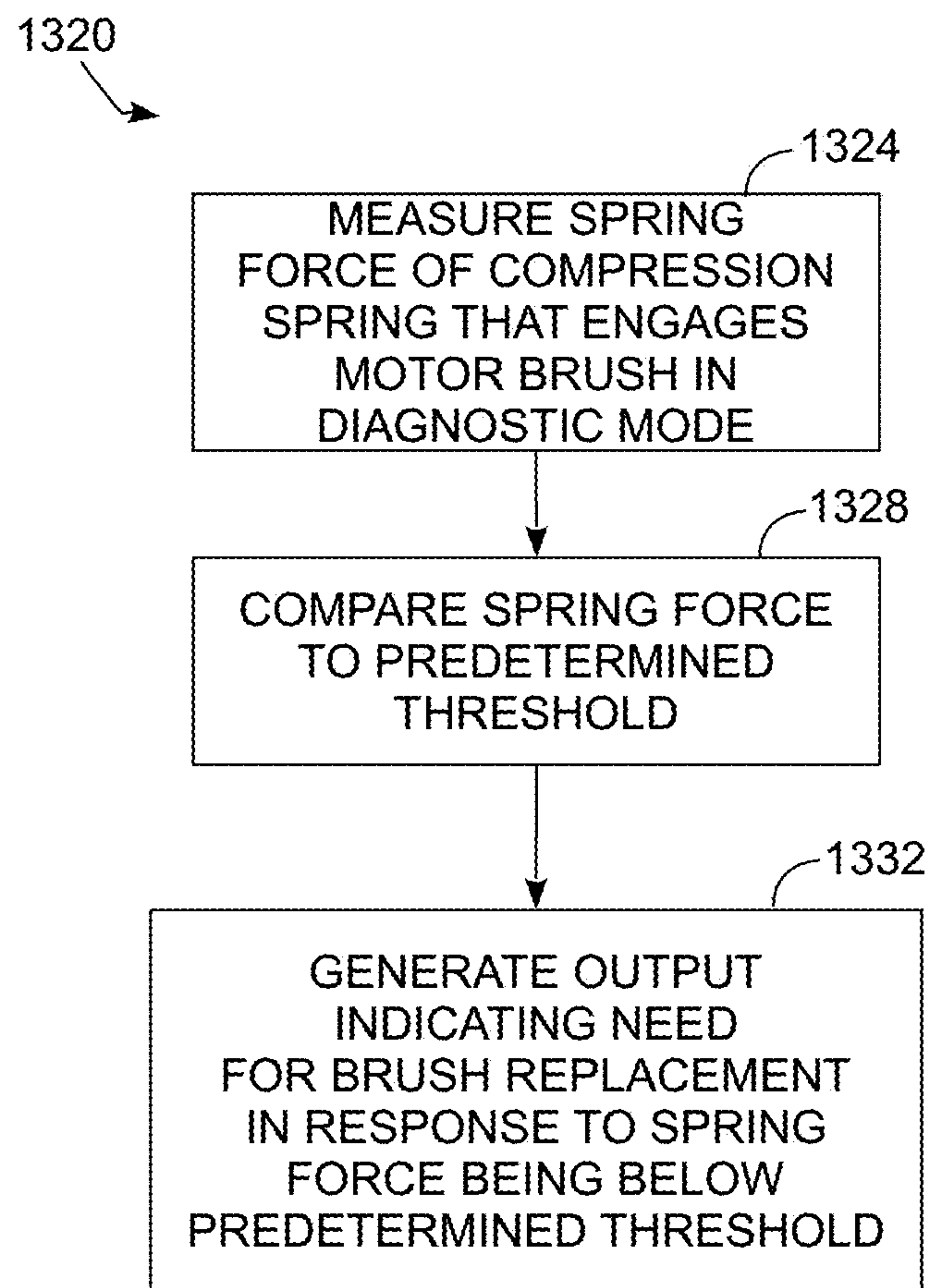


FIG. 11

**FIG. 12**



**FIG. 13A****FIG. 13B**

**FIG. 13C**



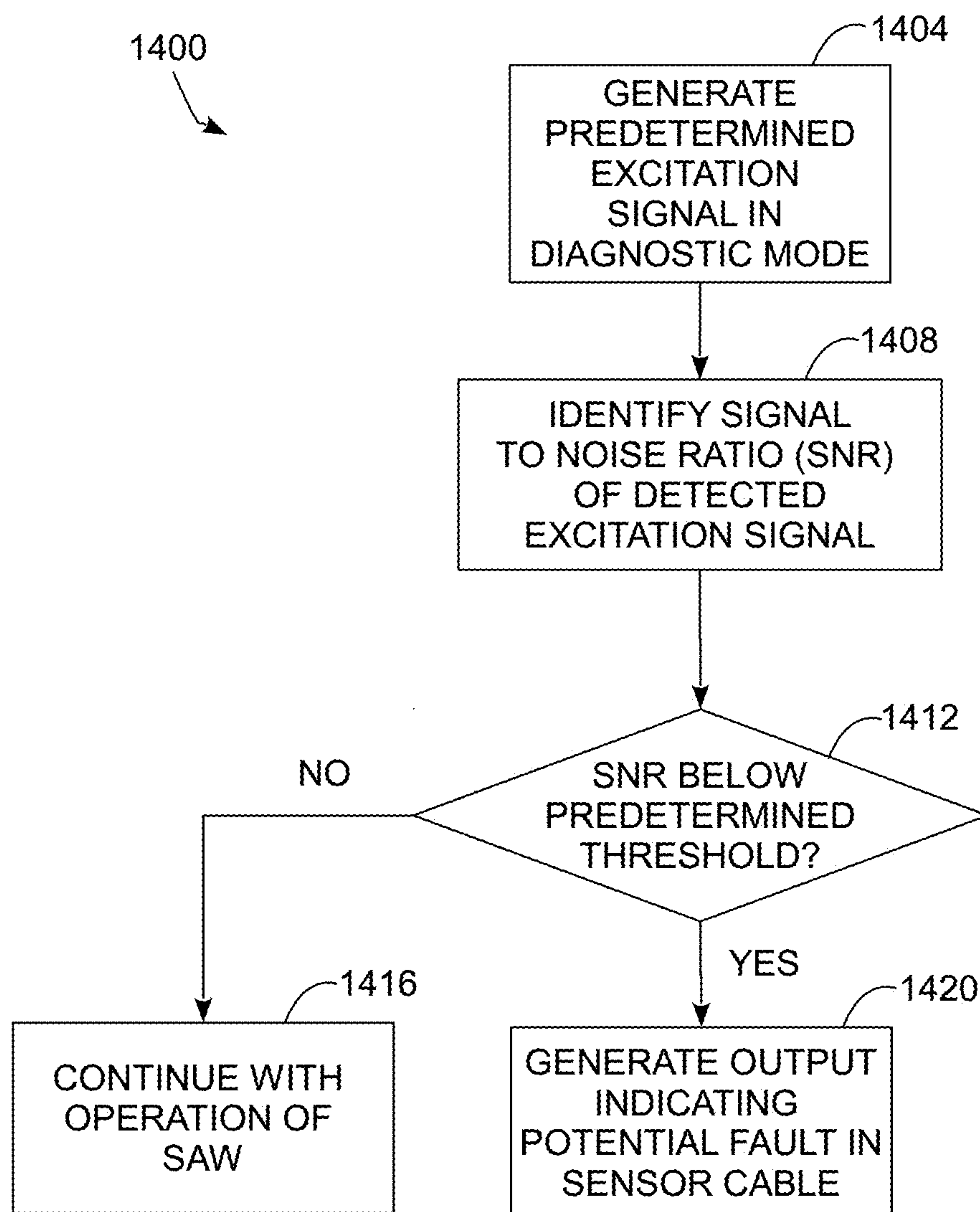


FIG. 14

## DIAGNOSTIC AND MAINTENANCE OPERATION FOR A SAW

### CLAIM OF PRIORITY

This application claims priority to U.S. Provisional Application No. 62/131,977, which is entitled "SYSTEM AND METHOD FOR CONTROL OF A DROP ARM IN A TABLE SAW," and was filed on Mar. 12, 2015, the entire contents of which are hereby incorporated by reference herein. This application also claims priority to U.S. Provisional Application No. 62/132,004, which is entitled "TABLE SAW WITH DROPPING BLADE," and was filed on Mar. 12, 2015, the entire contents of which are hereby incorporated by reference herein.

### CROSS REFERENCE

This application cross-references U.S. application Ser. No. 15/060,649 (issued as U.S. Pat. No. 9,914,239), which was filed on Mar. 4, 2016, the entire contents of which are hereby incorporated by reference herein. This application further cross-references copending U.S. application Ser. No. 15/060,656, which was filed on Mar. 4, 2016, the entire contents of which are hereby incorporated by reference herein. This application further cross-references copending U.S. application Ser. No. 15/060,670, which was filed on Mar. 4, 2016, the entire contents of which are hereby incorporated by reference herein. This application further cross-references copending U.S. application Ser. No. 15/060,709, which was filed on Mar. 4, 2016, the entire contents of which are hereby incorporated by reference herein. This application further cross-references copending U.S. application Ser. No. 15/060,742, which was filed on Mar. 4, 2016, the entire contents of which are hereby incorporated by reference herein.

### FIELD

This disclosure relates generally to power tools, and, more specifically, to systems and methods for performing diagnostics and maintenance in a saw that detects contact between an implement and objects.

### BACKGROUND

Detection or sensing systems have been developed for use with various kinds of manufacturing equipment and power tools. Such detection systems are operable to trigger a reaction device by detecting or sensing the proximity or contact of some appendage of an operator with some part of the equipment. For example, existing capacitive contact sensing systems in table saws detect contact between the operator and the blade.

FIG. 1 depicts a prior art capacitive sensing based detection system 90 that is incorporated with a table saw 1. The detection system 90 drives an excitation voltage that is electrically coupled to a movable blade 22 of the saw 1, and detects the current drawn from the blade 22. The amplitude or phase of the detected current and/or excitation voltage changes when the blade 22 comes into contact with an electrically conductive object (such as an operator's hand, finger or other body part, as well as work pieces). The characteristics of the changes are used to trigger the operation of a reaction system 92. The reaction system 92 disables operation of the blade 22 by, for example, applying a brake to cease motion of the blade 22 and/or by moving the blade

22 below the cutting area. One example of a reaction system 92 uses an explosive charge to drive a brake (not shown) into the blade 22 to arrest the motion of the blade 22. In addition, or instead, an embodiment of the reaction system 92 collapses a blade support member (not shown) to urge the blade 22 below the surface of the table 14.

The embodiment of the detection system 90 shown in FIG. 1 includes an oscillator 10 that generates a time-varying signal on line 12. The time-varying signal is any suitable signal type including, for example, a sine wave, a sum of multiple sine waves, a chirp waveform, a noise signal, etc. The frequency of the signal is chosen to enable a detection system to distinguish between contact with the first object, such as a finger or hand, and a second object, such as wood or other material, to be cut by the power tool. In the embodiment of FIG. 1, the frequency is 1.22 MHz, but other frequencies can also be used, as well as non-sinusoidal wave shapes. The oscillator 10 is referenced to the saw table 14 or other metallic structure as a local ground. As shown in FIG. 1, the blade 22 is disposed vertically in an opening defined by the saw table 14 (or work surface or cutting surface or platform).

The oscillator 10 is connected to two voltage amplifiers or buffers 16, 18 through the line 12. The first voltage amplifier 16 has an output connected to line 20, which operatively connects the output of the oscillator to the saw blade 22. A current sensor 24 operatively connects a signal from line 20 onto line 26 that is fed to an amplifier 28, which is connected to a processor 30 by line 32. The current sensor 24 is, for example, a current sense transformer, a current sense resistor, a Hall Effect current sense device, or other suitable type of current sensor. An output line 34 from the processor 30 is operatively connected to the reaction system 92 so that the processor 30 triggers the reaction system 92 if predetermined conditions are detected indicating, for example, contact between the blade 22 and the first object.

The signal on line 26 is indicative of the instantaneous current drawn by the blade 22. Because the saw blade 22 is in motion during operation of the table saw, the connection is made through an excitation plate 36, which is mounted generally parallel to the blade 22. The plate 36 is driven by the first voltage amplifier 16, and is configured with a capacitance of approximately 100 pF relative to the blade 22 in the embodiment of FIG. 1. The plate 36 is held in a stable position relative to the side of the blade 22. The excitation plate 36 is configured to follow the blade 22 as the height and bevel angle of the blade 22 are adjusted during operation of the saw 1.

The capacitance between the first object and the saw table 14 (or power line ground if one is present) is in the range of approximately 30-50 pF in the embodiment of FIG. 1. When the capacitance between the excitation plate 36 and the saw blade 22 exceeds the capacitance between the first object and the saw table 14, the detection thresholds are not unduly affected by changes in the plate-to-blade capacitance. In the configuration of FIG. 1, the plate 36 is arranged in parallel with the blade 22 on the side where the blade 22 rests against the arbor 37, so that changes in blade thickness do not affect the clearance between the blade 22 and the plate 36. Other methods of excitation, including contact through the arbor bearings or brush contact with the shaft or the blade, could be used to the same effect.

In the detection system 90, the second-amplifier 18 is connected to a shield 38, and the amplifier 18 drives the shield 38 to the same potential as the excitation plate 36. Also, sensors in the detection system 90 optionally monitor the level of electrical current drawn by the shield 38. The



3

shield 38 extends around the blade 22 underneath the table 14, and is spaced some distance away from the blade 22 on the top of the table 14 in the configuration of FIG. 1. The configuration of the shield 38 reduces the static capacitance between the blade 22 and the table 14, which acts as a ground plane if the table is not electrically connected to an earth ground. In various embodiments, the shield 38 is a continuous pocket of mesh, or some other type of guard that is electrically equivalent to a Faraday cage at the excitation frequencies generated by the oscillator 10. The shield 38 optionally includes a component that moves with the blade adjustments, or is large enough to accommodate the blade's adjustment as well as the various blades that fitted on the table saw. In the configuration of FIG. 1, the shield 38 moves with the blade adjustments, and includes a throat plate area of the table top 14.

The processor 30 performs various pre-processing steps and implements a trigger that enables detection of conditions indicative of contact between the first object and the blade 22. The processor 30 optionally includes one or more associated analog-to-digital (A/D) converters. The blade current signal from the current sensor 24 is directed to one or more of the A/D converters, which generate a corresponding digital signal. A blade voltage signal representing the voltage difference between the blade 22 and the excitation plate 36 is directed to an A/D converter to generate a digital blade voltage signal in some embodiments. The processor 30 receives the digitized signal and performs various digital signal processing operations and/or computes derivative parameters based on the received signal. The processor 30 analyzes or otherwise performs operations on the conditioned blade signal to detect conditions indicative of contact between the first object and the blade 22.

The prior art saw requires that the blade 22 be formed from an electrically conductive material that is also electrically connected to the arbor 37. Non-conductive blades and blades that include non-conductive coatings prevent proper operation of the contact detection system in the prior art saws. Additionally, the blade 22 and arbor 37 must be electrically connected to a ground plane for the contact detection system to operate effectively. The requirement for a ground connection to the blade also requires the saw 1 to be electrically connected to a proper ground, such as a ground spike, metal pipe, or other suitable ground, which requires that the table saw 1 remain in a fixed location. Other types of table saws include portable table saws that are transported between job sites where providing a ground connection may be inconvenient or impractical. Additionally, the requirement for a ground connection increases the complexity of setup and operation of non-portable table saws. Consequently, improvements to contact detection systems that do not require an electrical ground connection for the blade in portable and non-portable table saws would be beneficial.

### SUMMARY

In one embodiment, a method for monitoring brush wear in a motor of a saw has been developed. The method includes generating, with a sensor connected to a brush in a motor of the saw, a first signal corresponding to a level of wear in the brush, identifying, with a controller, a level of wear for the brush with reference to the first signal, and generating, with the controller and a user interface device, an output requesting replacement of the brush in response to the identified level of wear exceeding a predetermined threshold.

4

In a further embodiment, the method includes generating, with a current source in the motor, an electrical signal that passes through the brush, identifying, with the controller, a level of electrical resistance through the brush with reference to the first signal from the sensor, and identifying, with the controller, that the level of wear in the brush exceeds the predetermined threshold in response to the level of electrical resistance being below a predetermined threshold.

In a further embodiment, the method includes generating with the sensor the first signal corresponding to at least one of a level of electrical current or voltage in the brush.

In a further embodiment, the method includes generating, with the sensor, the first signal corresponding to a level of pressure exerted upon the sensor from a spring that biases the brush into contact with a commutator in the motor, and identifying, with the controller, that the level of wear in the brush exceeds the predetermined threshold in response to the level of pressure being below a predetermined threshold.

In a further embodiment, the method includes disabling, with the controller, operation of the motor in response to the identified level of wear exceeding the predetermined threshold.

In a further embodiment, the sensor generates the first signal during a diagnostic mode in which the motor is deactivated.

In another embodiment, a system for measuring brush wear of a motor in a saw has been developed. The system includes a motor in a saw, a brush in the motor, a sensor in the motor, the sensor being configured to generate a first signal corresponding to a level of wear in the brush, a user interface device, and a controller operatively connected to the motor, the sensor, and the user interface device. The controller is configured to receive the first signal from the sensor, identify a level of wear for the brush with reference to the first signal, and operate the user interface device to generate an output requesting replacement of the brush in response to the identified level of wear exceeding a predetermined threshold.

In a further embodiment, the system includes a current source in the motor configured to generate an electrical signal that passes through the brush and the sensor is configured to generate the first signal corresponding to at least one of a level of electrical current or voltage in the brush. The controller is configured to identify a level of electrical resistance through the brush with reference to the first signal from the sensor, and identify that the level of wear in the brush exceeds the predetermined threshold in response to the level of electrical resistance being below a predetermined threshold.

In a further embodiment, the sensor in the system is configured to generate the first signal corresponding to a level of pressure exerted upon the sensor from a spring that biases the brush into contact with a commutator in the motor. The controller is configured to identify that the level of wear in the brush exceeds the predetermined threshold in response to the level of pressure being below a predetermined threshold.

In a further embodiment, the controller is further configured to disable operation of the motor in response to the identified level of wear exceeding the predetermined threshold.

In a further embodiment, the sensor generates the first signal during a diagnostic mode in which the motor is deactivated.

In another embodiment, a method for operation of a saw with an implement reaction mechanism has been developed. The method includes detecting, with an object detection



## 5

system in the saw, contact between an object other than a work piece and an implement in the saw during operation of the saw, activating, with the object detection system, the implement reaction mechanism in the saw, incrementing, with a controller in the object detection system, a counter in a memory corresponding to a number of times that the implement reaction mechanism has been activated, and disabling, with the controller, operation of the saw in response to the counter exceeding a predetermined threshold.

In a further embodiment, the method includes resetting, with an external programming device, the counter in the memory during a maintenance operation, and enabling, with the controller, operation of the saw in response to the counter being reset.

In a further embodiment, the method includes generating, with a user interface device, an output indicating that the saw is disabled and requires service in response to the counter exceeding the predetermined threshold.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a prior art table saw including a prior art detection system for detecting contact between a human and a saw blade.

FIG. 2 is a schematic diagram of a table saw including an object detection system configured to identify if a saw blade in the saw contacts an object during rotation of the saw blade.

FIG. 3 is an external view of one embodiment of the table saw of FIG. 2.

FIG. 4 is a cross-sectional view of selected components including the blade, arbor, and sensor plate in the saw of FIG. 2.

FIG. 5A is an external view of a user interface device in the saw of FIG. 2.

FIG. 5B is a view of the user interface device of FIG. 5A with an external housing removed.

FIG. 5C is a profile view of the user interface device of FIG. 5B.

FIG. 5D is an exploded view of components in the user interface of FIG. 5A-FIG. 5C.

FIG. 6A is an exploded view of a charge coupled plate and arbor assembly in one embodiment of the saw of FIG. 2.

FIG. 6B is a profile view of the components depicted in FIG. 6A.

FIG. 7 is a schematic diagram depicting additional details of the object detection system and other components in one embodiment of the saw of FIG. 2.

FIG. 8A is a diagram depicting a sensing cable installed in one embodiment of the saw of FIG. 2.

FIG. 8B is a cut away diagram of components in a coaxial sensing cable.

FIG. 8C is a diagram depicting a connection of a first conductor in the sensing cable to a plate in the saw of FIG. 8A.

FIG. 8D is a diagram depicting a mount at one location for connection of a second conductor in the sensing cable to an implement enclosure in the saw of FIG. 8A.

FIG. 8E is a diagram depicting a mount at another location for connection of a second conductor in the sensing cable to an implement enclosure in the saw of FIG. 8A.

FIG. 9A is a schematic diagram of capacitive sensors arranged in a throat plate around a blade in one embodiment of the saw of FIG. 2.

FIG. 9B is a block diagram of a process for operation of a table saw using the capacitive sensors of FIG. 9A.

## 6

FIG. 10 is a block diagram of a process for monitoring activity of the implement reaction mechanism in one embodiment of the saw of FIG. 2 and disabling the saw for maintenance after the number of activations of the implement reaction mechanism exceeds a predetermined number.

FIG. 11 is a block diagram of a process for measuring profiles of different types of materials used in work pieces for the object detection system in the saw of FIG. 2.

FIG. 12 is a block diagram of a process for measuring the capacitance in the body of an operator of the saw to adjust operation of the object detection system in the saw of FIG. 2.

FIG. 13A is a schematic view of components in the motor of one embodiment of the saw of FIG. 2.

FIG. 13B is a block diagram of a process for measuring wear on a brush in the motor depicted in FIG. 13A based on electrical resistance in the brush.

FIG. 13C is a block diagram of a process for measuring wear on a brush in the motor depicted in FIG. 13A based on a pressure measurement for a spring that biases the brush to a commutator in the motor.

FIG. 14 is a block diagram of a process for diagnosing faults in the sensing cable of one embodiment of the saw of FIG. 2.

## DETAILED DESCRIPTION

For the purposes of promoting an understanding of the principles of the embodiments described herein, reference is now made to the drawings and descriptions in the following written specification. No limitation to the scope of the subject matter is intended by these references. This patent also encompasses any alterations and modifications to the illustrated embodiments as well as further applications of the principles of the described embodiments as would normally occur to one skilled in the art to which this document pertains.

As used herein, the term “power tool” refers to any tool with one or more moving parts that are moved by an actuator, such as an electric motor, an internal combustion engine, a hydraulic or pneumatic cylinder, and the like. For example, power tools include, but are not limited to, bevel saws, miter saws, table saws, circular saws, reciprocating saws, jig saws, band saws, cold saws, cutters, impact drives, angler grinders, drills, jointers, nail drivers, sanders, trimmers, and routers. As used herein, the term “implement” refers to a moving part of the power tool that is at least partially exposed during operation of the power tool. Examples of implements in power tools include, but are not limited to, rotating and reciprocating saw blades, drill bits, routing bits, grinding disks, grinding wheels, and the like. As described below, a sensing circuit integrated with a power tool is used to halt the movement of the implement to avoid contact between a human operator and the implement while the implement is moving.

As used herein, the term “implement reaction mechanism” refers to a device in a saw that retracts an implement, such as a blade or any other suitable moving implement, from a location with potential contact with a work piece or a portion of the body of a human operator, that halts the motion of the implement in a rapid manner, or that both retracts and halts the implement. As described below in a table saw embodiment, one form of implement reaction mechanism includes a movable drop arm that is mechanically connected to an implement, such as a blade, and an arbor. The implement reaction mechanism includes a pyrotechnic charge that is operated by an object detection system



in response to detection of contact between a portion of the body of an operator and the blade during operation of the saw. The pyrotechnic charges force the drop arm and blade below the surface of the table to retract the blade from contact with the operator in a rapid manner. In other embodiments of the implement reaction mechanism, a mechanical or electromechanical blade brake halts the movement of the blade in a rapid manner.

FIG. 2 depicts a schematic view of components in a saw 100, while FIG. 3 depicts an external view of one embodiment of the saw 100. The table saw 100 includes a table 104 through which a saw blade 108 extends for cutting work pieces, such as pieces of wood. The table saw 100 also includes an electric motor 112 that rotates an arbor 109 to drive the saw blade 108, an implement enclosure 118, and an implement reaction mechanism 132. While FIG. 2 depicts a cutting blade 108 for illustrative purposes, those of skill in the art will recognize that the blade 108 may be any implement that can be used in the saw 100 and that the references to the blade 108 are for illustrative purposes. In the saw 100, the implement enclosure 118 includes a height adjustment carriage and a bevel carriage that surround the blade 108, and the implement enclosure 118 is alternatively referred to as a blade enclosure or “shield” that surrounds the blade 108 or other suitable implement in the saw 100. As depicted in FIG. 3, a portion of the blade 108 extends upward through an opening in the throat plate 119 above the surface of the table 104. A riving knife 330 and blade guard 332 are positioned over the blade 108.

Within the saw 100, the implement enclosure 118 is electrically isolated from the blade 108, arbor 109, the top surface of the table 104, and a plate 120. In one embodiment, the implement enclosure 118 includes a throat plate 119 that is formed from an electrical insulator, such as thermoplastic. The throat plate 119 includes an opening to enable the blade 108 to extend above the surface of the table 104. The throat plate 119 is level with the surface of the table 104 and provides further electrical isolation of the blade 108, height adjustment carriage, and bevel carriage in the implement enclosure 118 from the surface of the table 104. The general configuration of the table 104, blade 108, and motor 112 are well known to the art for use in cutting work pieces and are not described in greater detail herein. Some components that are commonly used in table saws, such as guides for work pieces, blade height adjustment mechanisms, and blade guards are omitted from FIG. 2 for clarity.

The saw 100 further includes an object detection system 102 that includes a digital controller 140, memory 142, clock source 144, amplifier 146, transformer 150 and demodulators 143A and 143B. The object detection system 102 is electrically connected to the plate 120 and to the blade 108 via the implement enclosure 118 and arbor. The controller 140 in the object detection system 102 is operatively connected to the user interface device 110, motor 112, and implement reaction mechanism 132. During operation of the saw 100, the blade detection system 102 detects electrical signals that result from changes in the capacitance levels between the blade 108 and the plate 120 when an object contacts the rotating blade 108. An object can include a work piece, such as a piece of wood or other material that the saw 100 cuts during ordinary operation. The object detection system 102 also detects contact between the blade 102 and other objects, including potentially a hand or other portion of the body of the operator of the saw, and activates the implement reaction mechanism 132 in response to detection of contact between the blade 108 and objects other than

work pieces. Additional structural and operational details of the object detection system 102 are described in more detail below.

In the saw 100, the table 104 is electrically isolated from the saw blade 108, arbor 109, and other components in the saw enclosure 118 as depicted in FIG. 2 and FIG. 3. In one embodiment, the surface of the table 104 is formed from an electrically conductive metal, such as steel or aluminum. At the surface of the table 104, the electrically non-conductive throat plate 119 isolates the blade 108 from the surface of the table 104. Under the table 104, one or more electrically insulated mounts that secure the table 104 to the frame of the saw 100 but electrically isolate the table 104 from other components within the saw. As depicted in FIG. 2, in some embodiments the table 104 is electrically connected to ground 182 with an electrical cable. The ground connection reduces or eliminates the buildup of static electricity on the table 104, which prevents errant static discharges that can reduce the accuracy of object detection during operation of the saw 100.

In addition to the ground connection for the table 104, the blade 108 and implement enclosure 118 are connected to the ground 182 through high resistance cables that incorporate large resistors 180 (e.g. 1 MΩ resistors). The implement enclosure 118 is connected to ground 182 through a first cable and a resistor 180 that provides a high-resistance connection to ground. The blade 108 is also connected to the ground 182 via the arbor 109 through a second cable and resistor 180. The high-resistance connections to ground for the blade 108 and implement enclosure 118 also reduce the buildup of static charge on these components. While prior art detection devices require a low-resistance ground connection (e.g. a direct connection using an electrical cable with a resistance of less than 1Ω) in order to detect contact between a blade and an object using a low-impedance connection directly to earth ground, the high-resistance ground cables in the saw 100 are not required for operation of the object detection system 102. Instead the high-resistance cables merely reduce the effects of static electricity in the saw 100 to reduce potential false-positive detection events, but the object detection system 102 is still fully functional to detect contact between the blade 108 and an object without any ground connection. Alternative embodiments use different materials for either or both of the plate 120 and blade 108 to reduce the buildup of static electricity in the saw 100 and do not require any connection between the blade 108 or implement enclosure 118 and ground.

The table saw 100 includes a rip fence 304 that is mounted on rails 310 and 312. The rip fence 304 is configured to move to a predetermined position over the table 304 with an orientation that is parallel to the blade 108 to guide work pieces through the saw 100 during operation. In the saw 100, the rip fence 304 is electrically isolated from the table 104. For example, in FIG. 3 an electrically insulated thermoplastic rail mount 306 couples the rip fence 304 to the rail 310. A plastic guard (not shown) on the bottom of the rip fence 304 and another guard 320 on the top of the rip fence 304 electrically isolate the rip fence 304 from the table 104 in the saw 100. In some embodiments, the rip fence 304 includes another electrical insulator positioned on the side of the rip fence 304 that faces the blade 108 to ensure electrical isolation between the rip fence 304 and the blade 108 when a work piece engages both the rip fence 304 and blade 108 simultaneously.

Referring again to FIG. 2, the saw 100 also includes the detection system 102 that detects contact between objects and the blade 108 during operation of the saw 100. In one



configuration, some or all of the components in the detection system **102** are mounted to one or more printed circuit boards (PCBs). In the embodiment of FIG. 2, a separate PCB **172** supports a power supply **106** and a control TRIAC **174**. The power supply **106** receives an alternating current (AC) electrical power signal from an external power source, such as a generator or electrical utility provider, and supplies electrical power to the motor **112** through the TRIAC **174** and to supply electrical power to the components in the sensing system **102**. The separate PCBs for the sensing system **102** and power supply **172** isolate the digital controller **140** from the power supply **106** and TRIAC **174** to improve cooling of the digital electronics in the controller **140** and to isolate the controller **140** from electrical noise. In the embodiment of FIG. 2, the power supply **106** is a switched power supply that converts the AC power signal from an external power source to a direct current (DC) electrical power signal at one or more voltage levels to supply power to the controller **140**, clock source **144**, and amplifier **146**. The detection system **102** and the components mounted on the detection system **102** are electrically isolated from an earth ground. The power supply **106** serves as a local ground for the components mounted to the detection system **102**.

In the saw **100**, the plate **120** and the blade **108** form a capacitor **124** where a small air gap between the plate **120** and the blade **108** acts as a dielectric. The plate **120** is an electrically conductive plate such as a steel or aluminum plate that is positioned at a predetermined distance from the blade **108** with a parallel orientation between the plate **120** and the blade **108** to form two sides of the capacitor **124** with an air gap dielectric. The transformer **150** includes a first winding **152** and a second winding **154**. In the saw **100**, the plate **120** is a metallic planar member that is electrically connected to the winding **152** in the transformer **150**. The plate **120** is otherwise electrically isolated from the implement enclosure **118** and is electrically isolated from the blade **108** by a predetermined air gap to form the capacitor **124**. The plate **120** is also referred to as a charge coupled plate (CCP) because the plate **120** forms one side of the capacitor **124** in conjunction with the blade **108**. In one embodiment, a plastic support member holds the plate **120** in a predetermined position with respect to the blade **108**. The blade **108** and blade arbor **109** are electrically isolated from the enclosure **118**, plate **120**, the drop arm in the implement reaction mechanism **132**, and other components in the saw **100**. For example, in the saw **100**, one or more electrically insulated plastic bushings isolate the arbor **109** and blade **108** from the implement enclosure **118**, the drop arm in the implement reaction mechanism **132**, and other components in the saw **100**. Additionally, the saw blade **108** and arbor **109** are electrically isolated from ground. Thus, the blade object detection system in the saw **100** operates in an “open loop” configuration where the capacitor **124** is formed from the plate **120** and the blade **108** while the blade **108** and arbor **109** remain electrically isolated from the other components in the saw **100**. The open loop configuration increases the capacitance between the plate **120** and the saw blade **108** in comparison to the prior art sensing systems where the saw blade is electrically grounded. The larger capacitance in the saw **100** improves the signal to noise ratio for detection of a signal that indicates contact between a human operation and the saw blade **108**.

As depicted in FIG. 2, the plate **120** is electrically connected to one side of the first winding **152** in the transformer **150** while the implement enclosure **118** is electrically connected to the other side of the first winding

**152**. In one embodiment, the saw **100** includes a single coaxial cable that includes two electrical conductors to establish the two electrical connections. In one configuration, the center conductor element of the coaxial cable is connected to the plate **120** and the first terminal of the first winding **152** in the transformer **150**. The outer sheath of the coaxial cable is electrically connected to the blade **108** through the enclosure **118** and the arbor **109** and to the second terminal of the first winding in the transformer **150**. The structure of the coaxial cable provides shielding to transmit the electrical signals from the plate **120** and implement enclosure **118** while attenuating electrical noise that is present in the saw **100**.

FIG. 4 depicts a cross-sectional view of the blade **108**, arbor **109**, and plate **120** in more detail. In FIG. 4, electrically nonconductive bushings **404** and **408** engage the arbor **109**. The electrically nonconductive bushings **404** and **408** include, for example, layers of electrically insulated plastic, ceramic, or other insulators that electrically isolate the arbor **109** from other components in the saw **100**. In the illustrative example of FIG. 4, the bushings **404** and **408** include bearings that enable the arbor **109** to rotate during operation. The blade **108** only physically engages the arbor **109**, and remains electrically isolated from other components in the saw **100**. In FIG. 4, a plastic support member **412** holds the plate **120** in position at a predetermined distance from the blade **108** while electrically isolating the plate **120** from other components in the saw **100**.

FIG. 6A and FIG. 6B depict an exploded and front view, respectively, of the components depicted in FIG. 4. FIG. 6A depicts the plate **120** and the support member **412**, which are affixed to the support frame that holds the arbor **109** using a set of screws. To maintain electrical isolation between the plate **120** and the arbor **109** and other components in the enclosure **118**, the screws are either electrically non-conductive or the threaded holes in the support frame include electrically non-conductive threadings to maintain the electrical isolation. The support member **412** includes a lip **612** that surrounds the outer perimeter of the plate **120** and extends outward past the surface of the plate **120**. The lip **612** provides additional protection and electrical isolation to the plate **120** during operation of the saw **100**. In particular, the lip **612** prevents contact between the blade **108** and the plate **120** due to potential transient wobbles in the rotation of the blade **108** as the blade **108** cuts work pieces during operation of the saw **100**. FIG. 6B further depicts the lip **612** of the support member **412** that extends around the plate **120**.

FIG. 7 depicts additional details of one embodiment of the object detection system **102** and power supply and control PCB **172** of FIG. 2 in more detail. In the configuration of FIG. 7, some of the cables connecting different components in the saw **100** include ferrite chokes, such as ferrite chokes **708**, **738**, and **740** that are coupled to cables **724**, **736**, and **742**, respectively. The cable **742** connects the TRIAC **174** to the motor **112** and the ferrite choke **740** reduces noise in the electrical current that passes through the cable **742** to supply power to the motor **112** upon activation of the TRIAC **174**. As discussed in more detail below, the ferrite chokes **708** and **738** reduce noise in the data and power cables **724** and **736**, respectively, which connect the object detection system **102** to the power supply and control PCB **172**. In the configuration of FIG. 7, the sensing cable **720** that includes the first conductor connected to the plate **120** and the second conductor electrically connected to the saw blade **108** does not pass through a ferrite choke. Similarly, a motor tachometer cable (not shown) connecting the motor **112** to the



## 11

controller **140** does not pass through a ferrite choke. As is known in the art, the ferrite chokes filter high-frequency noise from the cables that are connected to the controller **140** and other components in the object detection system.

FIG. 7 also depicts thyristors **743A** and **743B**. The thyristor **743A** connects the third terminal of the transformer **150** to the demodulator **143A** for demodulation of the in-phase component of the sensing signal. The thyristor **743B** connects the fourth terminal of the transformer **150** to the second demodulator **143B** for the quadrature phase component of the sensing signal. The thyristors **743A** and **743B** are “two lead” thyristors, which are also referred to as Shockley diodes, that switch on in response to an input signal that exceeds a predetermined breakdown voltage but do not require a separate gate control signal to be placed in the switched on state. The thyristors **743A** and **743B** are configured with a breakdown voltage that is somewhat higher than the normal voltage amplitude of sensing signal to reduce the effects of random noise in the inputs of the demodulators **143A** and **143B**. However, if an object such a human hand contacts the blade **108**, then the input voltages exceed the breakdown threshold level of the thyristors **743A** and **743B** and both the thyristors **743A** and **743B** switch on to enable the spike and the sensing signal to pass to the demodulators **143A** and **143B**, respectively. The thyristors **743A** and **743B** are optional components in the embodiment of FIG. 7 and alternative configurations of the object detection system **102** omit these thyristors.

In FIG. 7, the data cable **724** that connects the controller **140** to the power supply **106** and TRIAC **174** on the power supply PCB **172** passes through the ferrite choke **708**. Additionally, a pull-down resistor **732** connects the data cable **724** between the controller **140** and the power supply PCB **172** to a local ground (e.g. a copper ground plane on the PCB of the object detection system **102**) to provide additional noise reduction in signals that are transmitted over the cable **724**. The pull-down resistor and ferrite choke enable the data cable **724** to carry control signals using a predetermined command protocol, such as I<sup>2</sup>C, over a long distance between the first PCB of the object detection system **102** and the second PCB **172** of the power supply **106** and TRIAC **174**. For example, in one configuration of the saw **100**, the data cable **724** has a length of approximately 0.75 meters and transmits the I<sup>2</sup>C signals from the controller **140** to the power supply **108** and command logic associated with the TRIAC **174**. The power cable **736** that provides electrical power from the power supply **106** to the controller **140** and other components in the object detection system **102** passes through the ferrite choke **738**. While FIG. 7 depicts a separate data cable **724** and power cable **736**, in another embodiment a single cable provides both power and data connectivity between power supply PCB **172** and the components in the object detection system **102**. The single cable embodiment also uses a ferrite choke to reduce the effects of noise in a similar manner to the configuration of FIG. 7.

FIG. 8A-FIG. 8E depict the coaxial cable that connects the plate **120** and blade **108** to the detection system **102** in more detail. FIG. 8A depicts an enclosure **802** that contains the PCB and other components in the SCU that implements the object detection system **102** and other control elements of the saw **100**. The sensing cable **720** is electrically connected to both the sensing plate **120** and the blade **108**. As depicted in FIG. 8A and FIG. 8B the sensing cable **720** is a coaxial cable with a first internal conductor **852**, an electrical insulator **856** that surrounds the inner conductor **852** and separates the inner conductors from a second metallic conductor **862**, and an exterior insulator **864** sur-

## 12

rounding the second conductor **862**. In the configuration of FIG. 8A, the first conductor **852** is connected to the plate **120** and to the first terminal of the transformer **150** in the object detection system **102** as depicted in FIG. 2. The second conductor **862** is electrically connected to the blade **108** and to the second terminal of the transformer **150** in the object detection system **102** as depicted in FIG. 2.

While FIG. 8B depicts a coaxial cable, an alternative embodiment employs a twisted pair cable that includes two different conductors that are twisted around one another in a helical pattern. One or both of the conductors in the twisted pair cable are surrounded by an electrical insulator to isolate the conductors from each other. Additionally, a shielded twisted pair cable includes an external shield, such as a metallic foil, that is wrapped around the twisted pair cable and reduces the effects of external electrical noise on the conductors in the twisted pair cable.

FIG. 8A depicts the connection of the single sensing cable **720** to the plate **120** at location **832** and to the bevel carriage and height adjustment carriage of the implement enclosure **118** at locations **836** and **838**. FIG. 8C depicts the connection of the first conductor in the sensing cable **720** to the plate **120** at location **832** in more detail. A metal retention clip **866** is affixed to the plate **120** and to the first conductor **852** in the sensing cable **720** to establish the electrical connection. In the configuration of FIG. 8C, the retention clip **866** is inserted between the plate **120** and the support member **412** to ensure a stable connection between the sensing cable **720** and the plate **120**. In some embodiments, the retention clip **866** is soldered to the plate **120**.

The second conductor **862** is electrically connected to the blade **108**, but since the blade **108** rotates during operation of the saw and since the blade **108** is typically a removable component, the second conductor **862** is not physically connected to the blade **108** directly. Instead, the second conductor is connected to the implement enclosure **118**. In some saw embodiments, the enclosure **118** actually includes multiple components, such as the height adjustment carriage and bevel carriage in the saw **100**. To ensure a consistent electrical connection, the second conductor in the single sensing cable **720** is connected to each of the height adjustment carriage and the bevel carriage to maintain a reliable electrical connection with the blade **108**. For example, in FIG. 8 the second conductor in the sensing cable **720** is connected to the height adjustment carriage at location **836** and to the bevel carriage at location **838**.

FIG. 8D and FIG. 8E depict two different mount locations that connect the second conductor in the sensing cable **720** to the implement enclosure **118** at two different locations including both the height adjustment carriage and bevel carriage. As depicted in FIG. 8D, the second conductor is electrically and physically connected to the implement enclosure **118** at location **836** using a connection mount **872**. The outermost insulator **864** is removed from the sensing cable **720** within the connection mount **872** to establish an electrical connection with the implement enclosure **118**. In some embodiments, the connection mount **872** is formed from a metal sleeve that surrounds and engages a portion of the second conductor **862** in the sensing cable **720**. As described above, the implement enclosure **118** is electrically connected to the arbor **109** and the blade **108**, and the cable mount **872** provides a reliable electrical connection between the second conductor **862** in the sensing cable **720** and the blade **108** through the height adjustment carriage. FIG. 8E depicts another configuration of a connection mount **876** that secures the sensing cable **720** at location **838** to the bevel carriage and provides an electrical connection between the



13

second conductor **862** in the sensing cable **720** and the implement enclosure **118**. In one embodiment, the connection mount **876** is also formed from a metal sleeve that surrounds a portion of the second conductor in the sensing cable **720** to establish the electrical connection with the blade **108** through the implement enclosure **118**.

As depicted in FIG. 2 and FIG. 7, the controller **140** is operatively connected to the power supply **106** and TRIAC **174** on the separate PCB **172** through a data line. In the embodiment of the saw **100**, the data line is a multi-conductor cable such as an HDMI cable and the controller **140** transmits command messages to the PCB **172** using the I<sup>2</sup>C protocol. The controller **140** optionally receives status data or data from sensors, such as onboard temperature sensors, from the PCB **172** using the I<sup>2</sup>C protocol. The ferrite choke **708** reduces electrical noise in the data cable **724** and the ferrite choke **738** reduces electrical noise in the power cable **736**. The tamp resistor **732** also reduces noise through the data cable **724**. In one embodiment, the data cable **724** includes a physical configuration that conforms to the High-Definition Multimedia Interface (HDMI) standard, which includes multiple sets of shielded twisted-pair conductors, although the data cable **724** does not transmit video and audiodata during operation of the saw **100**. In the embodiment of FIG. 2, the data cable has a length of approximately 0.75 meters to connect the separate PCBs **102** and **172**.

During operation, the controller **140** signals the TRIAC **174** to supply electrical current to the motor **112** through a gate in the TRIAC. Once triggered, the TRIAC **174** remains activated for as long as at least a predetermined level of electrical current from the power supply **106** passes through the TRIAC **174** to power the motor **112**. The power supply **106** varies the amplitude of the current that is delivered to the motor **112** to adjust the rotational speed of the motor **112** and saw blade **108**. To deactivate the motor **112**, the power supply reduces the level of power supplied to the TRIAC **174** below a predetermined holding current threshold and the TRIAC **174** switches off. In the embodiment of FIG. 2, the TRIAC **174** enables operation of the motor **112** at varying speed levels and activation/deactivation without requiring relays that are typically needed in prior art power saws. In the illustrative example of FIG. 2, the TRIAC **174** passes an AC electrical signal to the motor **112**, although alternative embodiments include DC motors that receive DC electrical power instead.

The controller **140** and associated components in the detection system **102** are sometimes referred to as a saw control unit (SCU). The SCU is electrically isolated from other components in the saw **100** with the exception of the power, control, and sensor data connections between the detection system **102** and other components in the saw **100**. In the saw **100**, the controller **140** also handles control of other operations in the saw **100** that are not directly related to the detection of object contact with the blade **108**, such as activating and deactivating the motor **112**. In the embodiment of FIG. 2, the SCU is located outside of the implement enclosure **118**, the detection system **102** is mounted to a non-conductive plastic support member, and the detection system **102** is oriented to avoid placing the ground plane of the detection system **102** in parallel with any metallic members within the saw **100** to reduce the transfer of electrical noise to the electrically conductive traces in the detection system **102**.

In the saw **100**, the clock source **144** and driving amplifier **146** in the sensing circuit generate a time varying electrical signal that is directed through a first winding **152** in the

14

transformer **150**, the capacitive coupling plate **120**, the blade **108**, and the implement enclosure **118**. The time varying electrical signal is referred to a “sensing current” because the controller **140** senses contact between the blade **108** and a portion of a human body with reference to changes in the amplitude of the sensing current. The time varying electrical signal is a complex valued signal that includes both an in-phase component and quadrature component. The sensing current passes through the first winding **152** in the transformer **150** to the plate **120**. The changes in the first winding caused by discharges between the plate **120** and the blade **108** produce an excitation signal in the second winding **154** of the transformer **150**. The excitation signal is another complex valued signal that corresponds to the sensing current passing through the first winding **152**.

The controller **140** in the sensing circuit is operatively connected to the motor **112**, the second winding **154** in the transformer **150**, a mechanical implement reaction mechanism **132**. The controller **140** includes one or more digital logic devices including general purpose central processing units (CPUs), microcontrollers, digital signal processors (DSPs), analog to digital converters (ADCs), field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs) and any other digital or analog devices that are suitable for operation of the saw **100**. The controller **140** includes a memory **142** that stores programmed instructions for the operation of the controller **140**, and data corresponding to a threshold of max-min variations, a variance threshold, or a frequency response threshold that are used to identify if samples obtained from a sensing current flowing through the blade **108** indicate that the saw blade **108** is rotating or is halted.

During operation of the sensing circuit, the clock source **144** generates a time varying signal, such as sinusoidal waveform, at a predetermined frequency. In the embodiment of FIG. 2, the clock source **144** is configured to generate a signal at a frequency of 1.22 MHz, which is known to propagate through the human body. The amplifier **146** generates the sensing current as an amplified version of the signal from the clock source **144** with sufficient amplitude to drive the transformer **150** and capacitor **124** for detection by the controller **140**. In the embodiment of FIG. 2, the saw **100** generates the sensing signal using amplitude modulation (AM), but in alternative embodiments the sensing signal is generated with a frequency modulation, phase modulation, or other suitable modulation technique.

During operation of the sensing circuit, the controller **140** receives the in-phase component I of the excitation signal in the second winding **154** through a first demodulator **143A** and the quadrature component Q of the excitation signal through a second demodulator **143B**. The transformer **150** isolates the sensing current flowing through the first winding **152**, plate **120**, saw blade **108**, and implement enclosure **118** from demodulators **143A** and **143B** that supply the in-phase and quadrature phase components of the signal, respectively, to the controller **140**. Since the demodulators **143A** and **143B** generate electrical noise, the transformer **150** reduces or eliminates the effects of the noise on the first winding **152** and sensing current. In one configuration, the transformer **150** is a 1:1 transformer where the first winding **152** and second winding **154** have an equal number of turns. In alternative configurations, the ratio of windings in the first winding **152** and second winding **154** are selected to either step-up or step-down the signal for demodulation and monitoring by the controller **140**. The controller **140** includes one or more ADCs, filters, and other signal processing devices required to generate digital representations of the amplitude



15

of the in-phase signal I and quadrature signal Q. The controller 140 identifies an amplitude of the sensing current A at a given time as a Pythagorean sum of the in-phase and quadrature components in each sample, as illustrated in the following equation:  $A = \sqrt{I^2 + Q^2}$ . The controller 140 measures the demodulated signal at a predetermined frequency, such as a 100 KHz sampling rate with a 10  $\mu$ sec period between each sample, to identify changes in the amplitude A of the complex valued signal.

As the motor 112 rotates the blade 108, the rotating blade 108 comes into contact with different objects, including blocks of wood and other work pieces. A small portion of the charge that accumulates on the blade 108 flows into the work piece. The electrical conductivity of the wood work piece is, however, quite low, and the controller 140 in the sensing circuit continues to enable the motor 112 to rotate the saw blade 108. For example, when the blade 108 engages a block of wood, the controller 140 typically measures a small change in the sensing current A, but the change in the sensing current is identified as corresponding to wood or another material with low electrical conductivity.

While work pieces, such as wood, have low electrical conductivity, another object, such as a part of the human body, has a much higher electrical conductivity and absorbs a much greater portion of the charge on the blade 108 as the part approaches the blade 108. In FIG. 2 a portion of a human body 164, such as a hand, finger, or arm, is represented by a charge cloud indicating the flow of charge from the blade 108 to the human body. The contact between the human body and the blade 108 effectively changes the capacitance level, since the human body and saw blade 108 both receive charge from the sensing current. The controller 140 identifies contact between the human body 164 and the blade 108 as a rapid increase in the amplitude A of the sensing current at the time when the human body 164 contacts the blade 108. In response to the rapid increase in the amplitude of the sensing signal, the controller 140 deactivates the motor 112, engages the implement reaction mechanism 132 to halt the motion of the blade 108, and optionally retracts the blade 108 before the blade contacts the human body 164.

In the configuration of FIG. 2, the human body has sufficient conductivity and capacity to draw charge from the blade 108 even when the detection system 102 is isolated from earth ground and when the human body 164 is isolated from earth ground, such as when a human operator wears shoes with rubber soles. Thus, while the detection system 102 and the human 164 do not share a common electrical ground, the controller 140 continues to identify contact between the human 164 and the blade 108 through identification of a rapid increase in the identified sensing current amplitude A. While the absolute value of the amplitude A may vary during operation of the saw 100, the controller 140 can still identify contact with the human 164 in response to the amplitude and time of the increase in the relative value of the amplitude A. During operation of the saw 100, the controller 140 is configured to identify contact with the human 164 and to deactivate the motor 112 and engage the implement reaction mechanism 132 to halt the saw blade 108 in a time period of approximately 1 millisecond.

In the saw 100, the controller 140 deactivates the electrical motor 112 in response to identification of contact between the blade 108 and a portion of a human. In the saw 100, the saw blade 108 generally continues rotating for a period of several seconds due to the momentum that the saw blade 108 accumulates during operation. The implement

16

reaction mechanism 132 is configured to either halt the saw blade 108 in a much shorter period of time, to drop the saw blade 108 below the table 104, which retracts the saw blade 108 from contact with the human, or to both halt and retract the blade 108. In the saw 100, the implement reaction mechanism 132 includes a drop arm that is mechanically connected to the saw blade 108. The implement reaction mechanism 132 also includes a pyrotechnic charge that is configured to push the drop arm down into the housing of the saw and away from the surface of the table 104. The controller 140 operates the pyrotechnic charge to move the drop arm and blade 108 downward in response to detection of contact between a portion of the body of the operator and the blade 108. The implement reaction mechanism retracts the blade 108 below the surface of the table 104.

In some configurations of the saw 100, the controller 140 is configured to lock out operation of the saw 100 after the pyrotechnic device is fired a predetermined number of times. For example, in the configuration of the saw 100 the implement reaction mechanism 132 includes a dual-pyrotechnic charge with a total of two "shots". Each operation of the implement reaction mechanism consumes one pyrotechnic charge in a "monoshot" operation. The operator removes and re-inserts the pyrotechnic device to place the second pyrotechnic charge in position to move the drop arm in a subsequent operation of the implement reaction mechanism 132. The controller 140 stores a record of the number of activations of the implement reaction mechanism 132 and prevents the saw 100 from being activated in a lockout process after the number of activations exceeds a predetermined number, such as one, two, or a larger number of activations. The controller 140 optionally sends a network notification to a service or warranty provider in embodiments of the saw 100 that are connected to a data network, such as the Internet, in the lockout operation. The lockout process enables service providers to diagnose potential issues with the operation of the saw 100 or procedures for use of the saw 100 in response to operation of the implement reaction mechanism 132 on a frequent basis.

In addition to sensing contact between an object and the saw blade 108 when the saw blade 108 is moving, the sensing circuit in the saw 100 is configured to identify if the saw blade 108 is moving when the motor 112 is deactivated. For example, the controller 140 identifies a period of time when the saw blade 108 continues to rotate after an operator operates the user interface 110 to activate the saw 100 to cut one or more work pieces, and subsequently opens the user interface 110 to deactivate the motor 112. The user interface 110 includes, for example, an activation/deactivation switch to operate the saw 100, a speed control input device, and status indicator lights that provide information about the operational status of the saw 100, such as if the saw is ready for operation or has developed a fault. The user interface device 110 is also referred to as a human machine interface (HMI).

The saw 100 is configured to be operated with the blade 108 and blade arbor 109 being isolated from electrical ground. The control electronics on the boards 102 and 172, the plate 120 and the implement enclosure 118 may not be connected to a true earth ground in some configurations, but these components share a common ground plane formed by, for example, a metal chassis of the saw or a ground plane formed on the circuit boards of 102 and 172. As described above, during the contact detection process the controller 140 identifies a spike in the current level for the sensing signal. However, electrical noise that is generated within the saw 100 could produce false positive or false negative



detection events since noise interferes with detection of the sensing signal. In the saw **100**, the PCBs **102** and **172** include ferrite core chokes that act as low-pass filters to reduce the effects of noise. Additionally, the power cabling and data cabling pass through ferrite cores to reduce the noise. The power supply **106** includes a ferrite choke and a thyristor to reject low-speed transient noise in the electrical power signal that is received from the electrical power grid, a generator, or other electrical power source.

FIG. 5A-FIG. 5D depict a portion of one embodiment of the user interface device **110** in more detail. FIG. 5A depicts an exterior view of a device status display including an external housing **502**, indicator lights **528A-528D**, and a covering for a short-range antenna **508**. During operation, the controller **140** activates one or more of the lights **528A-528D** to indicate different status information about the saw **100**. For example, the light **528A** indicates that the saw **100** is ready for operation. The light **528B** indicates that the implement reaction mechanism **132** has operated and that the pyrotechnic charge in the implement reaction mechanism **132** should be reset. The light **528C** indicates that the user should look up a fault code. The light **528D** indicates that the saw **100** requires maintenance to replace a component in the saw, such as a motor brush, or that the saw **100** requires maintenance after the implement reaction mechanism has operated for more than a predetermined number of times. As depicted in FIG. 5A, the indicator lights **528A-528D** provide a simplified interface. Alternative embodiments include a different arrangement of indicator lights or include additional input and output devices including, for example, video display screens, touch input devices, and the like.

While the display indicator lights **528A-528D** provide simplified direct output feedback to the operator for regular use with the saw **100**, in some circumstances the saw **100** transmits more complex diagnostic and configuration data to external devices. The controller **140** and user interface device **110** optionally transmit more complex diagnostic data and other information about the saw **100** to an external computing device via the short-range wireless antenna under the cover **512**. Examples of diagnostic data that the controller **140** collects and optionally transmits with the wireless transceiver and antenna **516** include, presence of voltage in the sensing circuit, the level of the sensor signal, status information to indicate if the pyrotechnic device (pyro) in the implement reaction mechanism **132** is armed or disarmed, generate a test signal for the pyro firing line without sending a signal with sufficient amplitude to trigger mono-shot operation of the pyro, detect presence or absence of the pyro, check a resistance range for corrosion or wire damage in the sensor cable connected to the plate **120** and implement enclosure **118** or other cables in the saw **100**, generate a "tackle pulse" to identify a wire break in the line that provides power to the motor **112**, and identify faults in the motor **112** during a power on self-test.

As depicted in FIG. 5B, the short-range wireless antenna **516** is formed from a predetermined arrangement of conductive traces on a PCB that supports the indicator lights **528A-528D**. FIG. 5B and FIG. 5C depict optically translucent caps **504A-504D** that form the exterior visible surface of each of the lights **528A-528B**, respectively. The external housing **502** protects the antenna **516** from external elements while enabling the antenna to be located on the exterior of the saw **100** to communicate with external electronic devices. The antenna **516** is operatively connected to a wireless transceiver, such as an NFC, Bluetooth, IEEE 802.11 protocol family compatible ("Wi-Fi"), or other suit-

able short-range wireless transceiver. An external electronic device, such as a smartphone, tablet, portable notebook computer, or other mobile electronic device receives data from the saw via a wireless communication channel and optionally transmits information to the saw **100** using the wireless communication channel. For example, a smartphone receives diagnostic data from the saw **100** and a software application that is run on the smartphone displays detailed diagnostic information to an operator or maintenance technician to assist in maintenance of the saw **100**. The software application optionally enables the operator to input configuration information for operational parameters of the saw **100** that are not directly accessible through the simplified input device **110**. For example, in one configuration the software application enables the operator to input a maximum RPM rate for the motor **112** and blade **108**. In another configuration, the software application enables the operator to transmit an identifier for a type of material that the saw **100** will cut during operation, such as different types of wood, ceramics, plastics, and the like.

In another configuration, the saw **100** includes a lockout mechanism to prevent operation of the saw **100** unless a mobile electronic device with an appropriate cryptographic key is within a predetermined distance of the saw **100**. The mobile electronic device transmits an encrypted authorization code to the saw **100** in response to a query from the saw **100** to unlock the saw **100** for operation. When the mobile electronic device is removed from proximity from the saw **100**, a subsequent query fails and the saw **100** remains inactive.

FIG. 5C depicts a profile view of the indicator lights **528A-528D**. Each light includes an optically translucent cap, such as the cap **504A** on the light **528A**, and an optically opaque body member **524A** directs light from a light source, such as an LED, to the translucent cap. In the indicator light **528A**, an LED **552** that is mounted on the PCB projects light through an opening in the opaque body member **524A** and the translucent cap **504A**. The opaque body member **524A** has a tapered shape with a narrow end surrounding a first opening for the LED **552A** and a wider end with a second opening that engages the translucent cap **504A**. The optically opaque member **524A** prevents the light from the LED **552A** from bleeding and producing false illumination in any of the other indicator lights **528B-528D**. The configuration of FIG. 5C enables the indicator lights in the user interface device **110** to operate in direct daylight conditions and prevents false illumination of incorrect indicator lights during operation.

FIG. 5D depicts an exploded view of select components from FIG. 5A-FIG. 5C. FIG. 5D depicts the indicator cap assembly **540**, which is formed from a molded plastic member that includes the translucent indicator light caps **504A-504D** for the lights **528A-528D**. The indicator cap assembly **540** also includes an attachment member, such as the hook **506** that is formed from the molded plastic member of the indicator cap assembly **540**, to secure the caps to other components in the user interface device **110**. The body member assembly **544** is another molded plastic member that includes the optically opaque body members **524A-524D** corresponding to the caps **504A-504D**. Each of the optically opaque body members **524A-524D** includes a first opening that aligns with one of the LEDs **552A-552D** and a second opening that engages one of the caps **504A-504D**. The body member assembly **544** also includes attachment members, such as the hooks **526**, which connect the opaque body members to other components in the user interface device **110**. The PCB **550** includes physical mounting loca-



tions and electrical connections for the operation of the user interface device **110**. In particular, FIG. **5D** depicts light emitting diodes (LEDs) **552A-552D** that are aligned with first openings in the corresponding opaque members **524A-524D** and that provide light for the caps **504A-504D** of the indicator lights **528A-528D**. The PCB **550** also includes the antenna **516**, which is formed from a predetermined pattern of conductive traces on the PCB, to enable wireless communication with the user interface device **110**. In some embodiments, the PCB **550** also supports a wireless transceiver directly, while in other embodiments the wireless transceiver is integrated with the controller **140**. The indicator cap assembly **540**, body member assembly **544** and PCB **550** are mounted to a base member **560**, which is a molded plastic member in the embodiment of FIG. **5D**. The base member **560** secures the components of the user interface device **110** to the exterior housing of the saw **100**.

FIG. **3** depicts the user interface device **110** mounted on the exterior of the housing of the saw **100**. The base member **560** attaches the components in the user interface device **110** to the exterior of the housing in the saw **100** where the indicator lights **528A-528D** are easily visible to the end user. Furthermore, the antenna **516** on the PCB **550** is positioned outside of the electrical shielding of the saw **100**, which provides both a clear view to enable communication with short-range external wireless devices and isolates the antenna **516** and any wireless transceivers on the PCB **550** from sources of electrical noise within the saw **100**. A data cable (not shown) connects the controller **140** mounted on the PCB within the housing of the saw **100** to the user interface device **110** on the exterior of the saw.

While the user interface device **110** depicted above includes lights and a wireless data interface, in some configurations the saw **100** includes additional data interface devices. For example, in one embodiment a universal serial bus (USB) or other suitable wired data connector is operatively connected to the controller **140**. The saw **100** includes a USB port near the rear of the bevel carriage. The USB port is hidden from ordinary operators, but maintenance personnel access the USB port by moving the bevel carriage to either the left or right extreme tilt position and locating the USB port through an opening at the back of the housing of the saw **100**. The USB port is connected to an external computing device to perform diagnostic and maintenance operations. The USB connection also enables maintenance personnel to update stored software programs in the memory **142** that the controller **140** executes during operation of the saw **100**.

Referring again to the saw configuration of FIG. **2**, in one operating mode the controller **140** in the saw **100** employs an adaptive thresholding process to identify the current spikes that correspond to the contact between an operator and the blade **108** to control operation of the implement reaction mechanism **132**. During the adaptive threshold process, the controller **140** identifies an average signal level for the sensing signal over a predetermined period of time (e.g. 32 sampling periods that last 320  $\mu$ sec at a sampling rate of 100 KHz). The controller **140** applies a predetermined bias value to the detected average level and uses the sum of the average and the bias level as an adaptive threshold. The controller **140** updates the average threshold based on comparatively small changes in the average level of the sensing signal that occur due to electrical noise, which prevents detection of a false positive contact event when the level of the sensing signal only changes due to electrical noise in the sensing signal. If contact between the operator and the blade **108** occurs, the rapid spike in the sensing

current exceeds the predetermined bias level and the controller **140** detects the contact and activates the implement reaction mechanism **132**.

In an optional embodiment of the adaptive threshold detection process, the controller **140** also identifies the signal to noise ratio (SNR) in the sensing signal in response to detecting a spike in the sensing signal current to further reduce the likelihood of false positive detection. The controller **140** identifies the SNR with reference to a mean value of the signal over a predetermined time window divided by the variance of the signal level over the same time window. In one configuration, the controller **140** performs a block computation process to reduce the computational complexity of identifying the SNR, which enable the controller **140** to identify the SNR within the operational timing constraints for operation of the implement reaction mechanism **132**. In the block computation process, the controller **140** identifies the mean values of the signal over comparatively short blocks (e.g. 32 sampling periods that last 320  $\mu$ sec at a sampling rate of 100 KHz) and stores the computed block mean values in a memory. The controller **140** then identifies the SNR over a series of the blocks, such as eight consecutive blocks of time over a period of 2560  $\mu$ sec in one embodiment.

The controller **140** identifies a single variance value for all of the blocks based on the difference between the eight "local" mean values that occur in each of the eight blocks and a single "global" average mean value for all eight blocks. The controller **140** identifies the SNR based on only the eight mean values and the identified variance value of instead of identifying the mean and variance over a total of 256 separate samples. The block computation process greatly reduces the computational power that is required to identify the SNR. The controller **140** continues identification of additional samples over time and updates the SNR sample after the oldest block is removed from the set of eight blocks to accommodate newer samples during operation. After identification of the SNR, the controller **140** identifies if the SNR level is below a predetermined minimum threshold at the time of detecting a sensing current spike that exceeds the detection threshold for contact between the operator and the blade **108**. If the SNR level is too low, which indicates a weak signal level in comparison to the detected noise level, then the controller **140** does not operate the implement reaction mechanism **132** to prevent false positive operation when the operator is not actually in contact with the blade **108**.

Another optional configuration of the adaptive thresholding process includes an operation to detect static discharge from the blade **108** and prevent a static discharge event from being incorrectly identified as contact between the operator and the blade **108**. During operation of the saw **100**, the rotating blade may accumulate static and discharge the static to components within the saw **100** or to an external object such as a work piece. The static discharge often produces a momentary positive or negative voltage spike in the sensing signal that is similar to the spike that occurs in response to contact between the operator and the blade **108**. However, the amplitude of the spike due to static discharge is often several times larger than any spike that is generated due to contact with the operator. Consequently, in some embodiments the controller **140** identifies human contact not only in response to the amplitude of the sensing signal exceeding the adaptive threshold, but also in response to the amplitude of the spike being below an upper bound threshold that is higher than the initial detection threshold to avoid a false-



positive operation of the implement reaction mechanism **132** in response to a static discharge event.

The adaptive thresholding process is useful in multiple operating modes of the saw **100** including operating modes in which the saw **100** performs “DADO” cuts. As is known to the art, during a DADO cut operation the blade **108** cuts a trench through all or a portion of a work piece, but does not completely cut the work piece into two separate parts. Many DADO cuts produce trenches that are thicker than a single saw blade, and the saw **100** operates with multiple saw blades placed together on the arbor **109** to form the thicker trenches. The multiple saw blades act as an antenna and receive electrical noise from various sources inside and outside of the saw **100**, which reduces the signal to noise ratio during DADO cuts.

In some embodiments, the controller **140** also detects contact between the operator and the blade **108** over a longer period of time during DADO cutting operations to account for the increased noise levels that are present in the detection signal. For example, in one configuration the controller **140** identifies a spike in the current level that exceeds the adaptive threshold for contact detection in a first sample period. In a high-noise environment, a noise spike may also produce the large spike that exceeds the adaptive threshold level. However, a true contact event produces a relatively consistent spike in the current that remains above the threshold for several sampling periods (e.g. up to 10 periods at a sampling rate of 100 KHz). The controller **140** identifies the change in the spike level over multiple sampling periods. If the amplitude of the spike remains high and does not change level by a large amount over several sampling periods, then the controller **140** identifies that the blade **108** is in contact with the operator and activates the implement reaction mechanism **132**. If, however, the controller **140** identifies large variations in the level of the sensing current spike, then the controller **140** identifies that the changes in the sensing current are due to noise and does not operate the implement reaction mechanism **132**. Even with the longer detection period, the total detection and operation time of the object detection system **102** occurs within a period of only a few milliseconds to maintain the effectiveness of the implement reaction mechanism **132**.

The adaptive thresholding process improves the accuracy of contact detection during the DADO cut. However, the adaptive thresholding process is not strictly required for use during DADO cut procedures, and the adaptive thresholding process is also effective for use in other modes of operation of the saw **100**.

During operation of the saw **100**, the controller **140** optionally performs a fault detection process to identify faults in the cable that connects the sensor plate **120** or implement enclosure **118** to the detection system **102**. The controller **140** identifies hard faults, such as full breaks in the cable, via a continuity test. So-called “soft faults” occur when the cable is at least intermittently connected, but the quality of the connection does not enable the sensing signal to reach the sensor plate **120** and for the controller **140** to detect the sensing current through the capacitor **124**. In one configuration, the controller **140** identifies soft faults prior to activation of the motor **112**. The controller **140** generates the sensing current through the sensing cable while the motor **112** remains deactivated and the level of electrical noise in the saw **100** is relatively low. If the amplitude or noise levels of the sensing signal deviate from expected values by more than a predetermined operational tolerance threshold, then the controller **140** identifies a soft fault in the sensing cable. The controller **140** produces an error signal through the user

interface device **110** and prevents activation of the motor **112** in response to detection of hard or soft faults in the sensing cable until the sensing cable is repaired or replaced.

In some embodiments, the saw **100** characterizes the capacitance levels of different operators through contact with a capacitive sensor at a predetermined contact location in the saw. For example, in one embodiment the saw **100** includes a metal handle that registers the capacitance, conductance, and other electrical properties of the hand of an operator when the operator grips the handle. In other embodiments, a capacitive sensor is located in a rail or other surface of the saw **100** that an operator contacts during typical operation of the saw **100**. The controller **140** receives sensor data corresponding to the electrical properties of each operator and adjusts the blade contact detection thresholds and other operating parameters to improve the accuracy of blade contact detection for each operator.

In some embodiments, the saw **100** performs pattern detection with the sensing signal to identify the state of the blade **108** during operation. For example, in one embodiment the controller **140** identifies elements of the sensing signal that correspond to tooth strikes between the blade **108** and a work piece. The controller **140** optionally uses a tachometer or other RPM sensor to identify the rotational rate of the blade **108**, and the controller **140** receives data corresponding to the size and number of teeth on the blade **108** to identify an expected frequency of tooth strikes as the blade **108** engages the work piece. The controller **140** uses the expected tooth strike frequency to assist in identification of sensing signals that may correspond to contact between the operator and the blade **108** or that merely corresponding to electrical noise that is produced when a tooth strikes the work piece.

In some embodiments of the saw **100**, the controller **140** stores identified profiles of the sensing signal while the saw **100** cuts different types of material. For example, the saw **100** cuts through different varieties of wood or pieces of wood with varying moisture levels to identify the amplitude and noise levels for the sensing signal that are detected while cutting a plurality of different types of wood or other material. The profile generation process optionally occurs at a factory prior to shipment of the saw **100**. During subsequent operation, the operator provides input to characterize the type of material that the saw **100** will cut, and the controller **140** retrieves a stored profile of the expected sensing signal parameters from a memory to assist in identification of the expected sensing signal when cutting the work piece.

FIG. 9A depicts another embodiment of an object detection sensors that is suitable for use in conjunction with the object detection system **102** in the saw **100** or in another saw embodiment. In FIG. 9A, the throat plate **119** incorporates capacitive sensors **904**, **908**, and **912**. Each of the sensors **904**, **908**, and **912** are capacitive sensors that can detect the presence of a human hand or other body part either in contact or close proximity to the surface of the corresponding capacitive sensor due to a change in capacitance around the sensor. By contrast, a work piece such as wood produces a much different change in capacitance to enable a controller, such as the controller **140** depicted in FIG. 2, to distinguish the work piece from a human body part. The capacitive sensors **904-912** are arranged along the cut direction **920**, which corresponds to the direction that a work piece travels as the blade **108** cuts the work piece. The capacitive sensor **904** is arranged in an area across the front of the saw blade **108**. The capacitive sensors **908** and **912** are



arranged conformal to the saw blade **108** on the left and right hand sides, respectively, as viewed from the front of the saw blade **108**.

As depicted in FIG. **9A**, each of the capacitive sensors **904-912** occupies a predetermined region of the throat plate **119**, such as the rectangular regions depicted in FIG. **9A** or another geometric shape. In some embodiments, the capacitive sensors **904-912** detect not only the presence of a human body part proximate to the corresponding sensor, but also a location of the human body part over the surface of the sensor and a velocity and direction of movement of the human body part over time. The thermoplastic throat plate **119** isolates the capacitive sensors **904-912** from the blade **108**, the surface of the table **104**, and from other components within the saw.

FIG. **9B** depicts a process **950** for operation of the capacitive sensors **904-912** in the saw **100**. In the description below, a reference to the process **950** performing a function or action refers to an operation of a controller to execute stored program instructions in association with other components in the saw to perform the function or action. The process **950** is described in conjunction with the embodiment of FIG. **9A** and the saw **100** for illustrative purposes.

Process **950** begins as the saw **100** is activated and the motor **112** moves the blade **108** to cut work pieces (block **954**). During operation, the capacitive sensors **904-912** generate the capacitive sensing signals to detect the presence of objects that are proximate to the surfaces of the capacitive sensors **904-912** in the throat plate **119** around the blade **108** (block **958**).

If the controller **140** identifies a change in the capacitance level of one or more of the capacitive sensors **904-912** based on a change in an RC time constant of the capacitive sensing signal, then the controller **140** detect the presence of an object, such as a work piece or human body part, in the region around the saw blade **108** prior to contact between the object and the saw blade (block **962**). For example, in some embodiments, the capacitive sensors **904-912** include capacitive sensing elements that form one plate in a capacitor and an electrically non-conductive dielectric that covers the capacitive sensing element and covers the surface of the capacitive sensors **904-912**. An oscillator in the capacitive sensors generates a time-varying capacitive sensing signal using an RC circuit formed from the capacitive element in each sensor and a predetermined resistor. As is known in the art, the RC time constant changes in response to a change in the size of the capacitance  $C$  in the RC circuit, and the capacitive sensor or an external control device identifies contact with objects based on changes in the time-varying signal. An object positioned over the surface one of the sensors **904-912** acts as the second plate in a capacitor and produces a change in the capacitance level of the sensor.

If the controller **140** identifies that there is no object proximate to the capacitive sensors (block **962**) or that a detected object produces a minimal change in capacitance that corresponds to a work piece but not a human body part (block **966**) then the saw **100** continues operation to cut a work piece (block **970**). Electrically conductive objects, such as a finger or other body part of a human operator, produce comparatively large changes in capacitance while electrically nonconductive objects, such a wood work pieces, produce small changes in the capacitance level. As described above, the characteristics of a work piece such as wood generate a change in capacitance in the sensors **904-912** that is sufficiently distinct from a human body part

to enable the controller **140** to distinguish between the work piece and a human body part that is in close proximity to the capacitive sensors **904-912**.

During process **950**, if the capacitive sensors generate a signal corresponding to a sufficiently large change in capacitance that corresponds to the presence of a hand or other body part in close proximity to the capacitive sensors **904-912**, then the controller **140** generates a warning output, deactivates the motor **112**, or activates the implement reaction mechanism **132** prior to the object contacting the blade **108** (block **974**). In a configuration where the detected object has not actually touched the blade but has moved within a predetermined distance of the blade, the controller **140** deactivates the motor **112** to enable the saw blade **108** to come to a halt but does not engage the implement reaction mechanism **132** unless the object actually contacts the blade as detected using the object detection system **102** described above. In other embodiments, if the capacitive sensors **904-912** detect an object corresponding to a human body part, the controller **140** generates a warning signal, such as a light that is visible to the operator on the table **104**, for the operator prior to deactivating the motor **112** or operating the implement reaction mechanism **132**. In some embodiments the object detection system **102** operates the implement reaction mechanism **132** if the object contacts the blade **108** prior to the blade **108** coming to a complete halt or prior to the object coming into contact with the blade **108**.

In some embodiments of the process **950**, the capacitive touch sensors **904-912** each include a two-dimensional grid of sensing elements that enable the touch sensors to generate multiple capacitive detection signals corresponding to the position within the two-dimensional region covered by each of the capacitive sensors. In some configurations, the controller **140** generates a warning signal if a human body part object is detected at a first position that is over one of the sensors **904-912** but beyond a first predetermined distance from the blade **108** and then deactivates the motor **112** if the object moves with the predetermined distance of the blade **108**. Furthermore, the controller **140** or other control device identifies a path of movement and velocity of the object based on a series of object locations that the individual sensing elements in the capacitive sensors **904-912** generate over time. If the path of movement indicates that an object, such as a human hand, has a high likelihood of contacting the blade **108** at some point along the path, then the controller **140** deactivates the motor **112** or generates the warning output as described above. Additionally, in some configurations the controller **140** activates the implement reaction mechanism **132** to retract the blade **108** or other implement prior to actual contact between the hand or other body part of the operator. For example, if the detected location of a hand of the operator is within a predetermined distance of the blade **108** or the path of movement of the hand over the capacitive sensors has a trajectory that could with the blade **108**, then the controller **140** optionally activates the implement reaction mechanism **132** before the contact with the blade **108** actually occurs. Of course, the capacitive sensors **904-912** and the process **950** can be implemented in tandem with the operation of the object detection system **102** that is described above to detect the presence of a body part of the operator in proximity to the blade **108** and to detect actual contact between the body part and the blade **108**.

In addition to the operation of the object detection system **102** that is described above, the saw **100** is further configured to perform different configuration and diagnostic processes to maintain reliability and enable operation of the saw



25

with a wide range of different materials. For example, the saw **100** is configured to maintain a record of the number of times that the implement reaction mechanism has been activated to ensure that the saw **100** receives proper maintenance.

FIG. **10** is a block diagram of a process **1000** for monitoring the operation of the implement reaction mechanism in the saw. In the discussion below, a reference to the process **1000** performing a function or action refers to the operation of a controller to execute stored program instructions to perform the function or action in association with one or more components in the saw. The process **1000** is described in conjunction with the saw **100** for illustrative purposes.

Process **1000** begins upon activation of the implement reaction mechanism (block **1004**). In the saw **100**, the controller **100** activates the implement reaction mechanism **132** in response to detection of contact between an object, such as the hand of the operator, other than a work piece. In one embodiment of the saw **100**, a pyrotechnic charge in the implement reaction mechanism **132** fires to retract the blade **108** below the level of the table **104**. The controller **140** increments a counter held in a non-volatile portion of the memory **142** to maintain a record of the number of times that the implement reaction mechanism has been activated during operation of the saw **100** (block **1008**). As is known to the art, the non-volatile memory, such as a solid-state or magnetic data storage device, retains stored data over a long period of time even when the saw **100** is deactivated and disconnected from electrical power.

The process **1000** and the operation of the saw **100** continues while the total number of activations of the implement reaction mechanism **132** remains below a predetermined threshold (e.g. five activations of the implement reaction mechanism **132**) (block **1012**). If the number of activations of the implement reaction mechanism exceeds the predetermined threshold (block **1012**) then the controller **140** disables operation of the saw **100** until the saw **100** undergoes a maintenance procedure (block **1016**). For example, in one configuration the controller **140** ignores any input signals from the user interface **110** to activate the saw **100**, and the motor **112** remains deactivated while the saw **100** is disabled. The controller **140** optionally generates an output indicated signal via the user interface **110** to alert the operator that the saw **100** is disabled and requires maintenance.

The process **1000** continues during a maintenance operation. In addition to any required maintenance to repair or replace mechanical or electrical components in the saw **100**, the maintenance operation further includes resetting the counter value in the memory of the saw **100** to return the saw to operation (block **1020**). In one embodiment, the maintenance process includes connection of an external programming device, such as a PC or other computerized programming device, to a maintenance port within the saw **100**, such as a universal serial bus (USB) port, to both retrieve diagnostic data from the memory **142** and reprogram the memory **142** to reset the counter that stores the number of times that the implement reaction mechanism has been activated. The use of the external programming device enables the saw **100** to be re-enabled for use after the maintenance process while remaining disabled until the saw undergoes proper maintenance.

The process **1000** ensures that the saw **100** remains disabled until receiving maintenance in the event of an unusually large number of activations of the implement reaction mechanism **132**. The maintenance operation ensures that all components within the saw **100** are operating

26

properly and that the object detection system **102** accurately detects contact between an object other than a work piece and the saw blade **108**.

As described above, the object detection system **102** receives input signals in response to contact between the blade **108** and any object, including both work pieces which the saw cuts during normal operation, and other objects including potentially a body part of the saw operator that results in activation of the implement reaction mechanism. During operation of the saw **100**, the object detection system **102** receives input signals corresponding to changes in the capacitance levels in the capacitor **124** formed by the plate **120** and blade **108** corresponding to both contact between work pieces and potential contact with objects other than work pieces. For example, in some situations wood with high moisture content has the potential to be confused with a portion of the body of a human operator during operation of the saw. FIG. **11** depicts a process **1100** that generates profiles of the signals generated by different types of material in various work pieces to improve the accuracy of object detection. In the discussion below, a reference to the process **1100** performing a function or action refers to the operation of a controller to execute stored program instructions to perform the function or action in association with one or more components in the saw. The process **1100** is described in conjunction with the saw **100** for illustrative purposes.

Process **1100** begins as the saw operates with the object detection system **102** enabled but the implement reaction mechanism **132** disabled (block **1104**). The operation of the saw **100** without the implement reaction mechanism being enabled occurs under controlled conditions such as at a facility of the manufacturer or an approved maintenance facility. During the process **1100**, the saw cuts various materials in work pieces that are suitable for use with the saw **100** but have the potential to produce sensing signals that could be misinterpreted as corresponding to a human body part or other object that should trigger the implement reaction mechanism **132** upon contact with the spinning blade **108**.

Process **1100** continues as the saw **100** records sensing signals in the object detection system **102** that are produced at predetermined times when the work piece initially contacts the blade **108**, during the cut as the work piece moves past the blade **108**, and at the time of completion of the cut when the work piece disengages from the blade **108** (block **1108**). The recorded sensing signal information typically includes spikes in the sensing signal that correlate to changes in the capacitance level in the capacitor **124**. For example, the initial spike that occurs when the work piece initially contacts the rotating blade **108** may be similar to the initial spike that is generated when an object other than the work piece initially contacts the rotating blade **108**.

In another embodiment of the process **1100**, the saw **100** includes additional sensors other than the capacitive sensor formed by the capacitor **124** that can detect characteristics of the work piece material that can be distinguished from the body of a human operator. For example, one embodiment further includes one or more infrared sensors that are mounted on the riving knife **330** that is depicted in FIG. **3**. The infrared sensors generate a profile of the frequency response of infrared light that is reflected from the work piece. The controller **140** is operatively connected to the infrared sensors to record the frequency response of the material in the work piece.

Process **1100** continues as the controller **140** or a processor in an external computing device identifies differences between the recorded sensing signal and the predetermined



sensing signal profile for an object that would trigger the implement reaction mechanism in the saw **100** (block **1112**). For example, as described above the controller **140** uses an adaptive thresholding process to identify spikes in the sensing current that correspond to a hand or other portion of the human body when in contact with the blade **108**. The spike corresponding to the contact with the human hand includes both an amplitude profile and time profile. The controller **140** identifies differences in the amplitude and duration between the predetermined profile for a human body part and the initial spike that occurs when the work piece first contacts the rotating blade **108** and any subsequent spikes that occur as the blade **108** cuts the work piece and disengages from the work piece.

The controller **140** or external processor then generates a detection profile that is specific to the test material based on the differences between the recorded sense signals and the predetermined object detection profile for the human body (block **1116**). In one embodiment, the controller **140** generates a profile with a range of amplitude values around the amplitude of the recorded spike in the sensing signal when the blade **108** engages the predetermined material in the work piece. The range of values for the amplitude of the spike does not include the threshold amplitude for the spike amplitude for the predetermined profile of the human operator to ensure that the controller **140** does not incorrectly identify a sensing signal corresponding to a human operator as a work piece. Thus, the size of the range of amplitude values that correspond to different work pieces varies based on the differences between the recorded spikes produced through contact between the blade **108** and the work piece material and the predetermined profile corresponding to a human body. The controller **140** similarly generates a time range corresponding to the duration of the spike in the sensing signal from the work piece based on differences between the time range of the spike from the work piece and an expected duration of the spike in the profile for contact with a human body. The updated profile enables the controller **140** to distinguish between sense signals from the capacitor **124** that correspond to contact between the blade **108** and a work piece of a predetermined type of material compared to potential contact with a portion of the human body.

As noted above, in an alternative embodiment the controller **140** generates a profile based on the data from the infrared sensors to identify the frequency response range of the material in the work piece and distinguish the frequency response range from a predetermined frequency response range that is associated with a human operator. The controller **140** uses a predetermined response range for the operator that is stored in the memory **142** to ensure that the frequency response range in the profile of the material does not overlap the predetermined profile for the human operator. For example, in one configuration the memory **142** stores a frequency response profile for near infrared responses that have a peak response at wavelengths of approximately 1080 nm and a minimum response at wavelengths of approximately 1580 nm for a wide range of human skin tones. Other types of materials for various work pieces have peak and minimum infrared frequency responses at different wavelengths, and the controller **140** generates a profile with a range of frequency responses for both peak and minimum response values at wavelengths that correspond to work pieces but do not overlap with the wavelengths corresponding to the responses of human skin.

During process **1100**, the updated profile for the test material is stored in the memory **142** (block **1120**). During subsequent operations with both the object detection system

**102** and implement reaction mechanism **132** being enabled, the controller **140** uses the stored profile information for the test material to reduce potential occurrences of false positive detection events when changes in the sensing signal that occur due to contact between the work piece and the saw blade **108** are misinterpreted as corresponding to contact between the operator and the saw blade. For example, if the saw **100** is cutting a particular type of material that is stored in a profile in the memory **142**, then the controller **140** continues to operate the saw **100** as long as any spikes in the sensing signal in the object detection system **102** remain within the amplitude and time duration ranges for the stored profile corresponding to the material type. In some configurations, the memory **142** stores profiles for multiple types of material that the saw **100** cuts during operation. The operator optionally provides an input to the saw **100** that specifies the type of material to be cut to enable the controller **140** to use a stored profile for the appropriate type of material in the work piece.

As described above, the object detection system measures changes in the sensing signal through the capacitor **124** in response to contact between objects and the rotating saw blade **108**. The memory **142** stores predetermined threshold information that the controller **140** uses with the adaptive threshold process described above to detect contact between the body of the human operator and the blade **108**. However, the bodies of individual human operators may exhibit different capacitance levels both between individuals and the capacitance level of one individual may vary over time for a variety of reasons. Examples of factors that affect the capacitance levels of operators include, but are not limited to, the temperature and ambient humidity in the environment around the saw, the physiological makeup of each operator, the perspiration level of the operator, and the like. FIG. **12** depicts a process **1200** for measuring the level of capacitance of an individual operator during operation of the saw **100** to enable the saw **100** to adjust the object detection thresholds for different individuals. In the discussion below, a reference to the process **1200** performing a function or action refers to the operation of a controller to execute stored program instructions to perform the function or action in association with one or more components in the saw. The process **1200** is described in conjunction with the saw **100** for illustrative purposes.

Process **1200** begins as the saw **100** measures a capacitance level of the operator through a capacitive sensor that is formed in a handle or other predetermined contact location on a surface of the saw **100** that the operator touches during operation of the saw (block **1204**). Using the illustration of FIG. **3** as an example, capacitive sensors in one or more of the rip fence **304**, the front rail **310**, the bevel adjustment handle **352**, the height adjustment handle **354**, or other surfaces of the saw that the operator touches during operation generate measurements of the capacitance level in the hands of the operator. The operator does not need to remain in continuous contact with the capacitive sensor during operation of the saw **100**, but the controller **140** optionally updates the measured capacitance level when the operator touches one or more of the capacitive sensors.

Process **1200** continues as the controller **140** modifies the threshold level for detection of contact with an object, such as the body of the operator, other than the work piece (block **1208**). The controller **140** decreases the default spike amplitude detection threshold for the sensing signal in response to a measured capacitance level that is less than a predetermined default level, which can occur when the operator has unusually dry skin or other environmental factors reduce the



effective capacitance in the body of the operator. The controller **140** modifies the threshold based on the difference between a default capacitance level that is appropriate for a wide range of human operators and the measured capacitance level that may be higher or lower than the default level. Reducing the threshold level effectively increases the sensitivity for detection between the operator and the saw blade **108** in the saw **100**. The controller **140** optionally increases the threshold in response to an identification of a large capacitance value in the operator. In some embodiments the controller **140** limits the maximum threshold level for object detection to ensure that the object detection system **102** retains the capability to detect contact between the operator and the blade **108** since increasing the detection threshold level effectively reduces the sensitivity of the object detection system **102**.

Process **1200** continues as the saw **100** operates to cut work pieces and the object detection system **102** uses the modified detection threshold to detect potential operator contact with the blade **108** (block **1212**). As described above, if the hand or other body part of the operator contacts the rotating blade **108**, the controller **140** compares the amplitude of the measured spike in the sensing signal through the capacitor **124** to the modified threshold using the adaptive thresholding process described above. Since the controller **140** modifies the detection threshold based on the measured capacitance of the operator, the process **1200** enables the saw **100** to detect contact between the operator and the saw blade **108** with improved accuracy.

In the saw **100**, the motor **112** includes one or more brushes that engage a commutator. The use of brushes in electric motors is well-known to the art. Over time, brushes experience wear, which reduces the efficiency of the motor and worn brushes often generate sparks. The sparks can be detrimental to operation of the motor **112** and in some circumstances the sparks generate electrical noise that is detected by the object detection system **102**. FIG. **13A** depicts an example of the shaft **1350**, commutator **1354**, and brushes **1358A** and **1358B** in the motor **112**. Springs **1362A** and **1362B** bias the brushes **1358A** and **1358B**, respectively, into contact with the commutator **1354**. In many embodiments, the brushes **1358A** and **1358B** are formed from graphite. In the motor **112**, the mounts **1366A** and **1366B** are formed in a housing of the motor **112** and engage the springs **1358A** and **1358B**, respectively. In one embodiment, the mounts **1366A** and **1366B** include pressure sensors that measure the compressive force applied through the springs **1362A** and **1362B**. In another embodiment, the mounts **1366A** and **1366B** generate sensing currents through the springs **1362A** and **1362B** and the corresponding brushes **1358A** and **1358B** to identify the electrical resistance levels through the brushes.

Since worn brushes not only reduce the efficiency of operation of the motor **112**, but may introduce additional electrical noise into the sensing signal for the object detection system **102**, the saw **112** optionally detects brush wear in the motor **112** and generates an output to indicate that worn brushes should be replaced via the user interface **110**. FIG. **13B** depicts a first embodiment of a process **1300** for measuring brush wear in the motor **112**. In the description below, a reference to the process **1300** performing an action or function refers to the operation of a controller, such as the controller **140** in the saw **100**, to execute stored program instructions to perform the function or action in conjunction with other components in the saw **100**.

During process **1300**, an electrical source positioned in each of the mounts **1366A** and **1366B** generates an electrical

current through the corresponding brushes **1358A** and **1358B** (block **1304**). In one embodiment, the current passes through the cables that are connected to the brushes **1358A** and **1358B** for normal operation of the brushes **1358A** and **1358B** in the saw **100**. In another configuration, the current passes through the springs **1362A** and **1362B** and the corresponding brushes **1358A** and **1358B**. The current is generated during a diagnostic mode when the saw motor **112** is otherwise deactivated and the level of the electrical current used in the process **1300** is well below a drive current that produces rotation in the motor shaft **1350** during operation of the motor **112**. During process **1300**, the controller **140** or a controller that is integrated with the motor **112** measures an electrical resistance level through the brushes and compares the measured electrical resistance level to a predetermined resistance threshold (block **1308**). The measurement of the electrical resistance level includes, for example, a measurement of a voltage level or current level for the electrical current that flows through each of the brushes **1358A** and **1358B** in the diagnostic mode and an application of Ohm's law to find the resistance (e.g.  $R=E/I$  for a measured voltage  $E$  and predetermined current  $I$  or predetermined voltage  $E$  and measured current  $I$ ). Once the resistance drops below a predetermined threshold, the controller **140** generates an output signal via the user interface **110** to indicate that the brushes should be replaced (block **1312**). The resistance drops as the brushes wear and grow thinner, which reduces the total resistance through the springs **1362A** and **1362B** and the corresponding brushes **1358A** and **1358B**. In some configurations, the controller **140** also disables operation of the saw **100** until any worn brushes have been replaced and the controller **140** performs the process **1300** again to confirm that the new brushes are no longer worn.

FIG. **13C** depicts a second embodiment of a process **1320** for measuring brush wear in the motor. In the description below, a reference to the process **1320** performing an action or function refers to the operation of a controller, such as the controller **140** in the saw **100**, to execute stored program instructions to perform the function or action in conjunction with other components in the saw **100**.

In the process **1320**, the spring mounts **1366A** and **1366B** each include a pressure sensor that measures the compressive force of the corresponding springs **1362A** and **1362B** during a diagnostic mode when the motor **112** is deactivated (block **1324**). As the brushes **1358A** and **1358B** experience wear, the corresponding springs **1362A** and **1362B** expand to bias the brushes onto the commutator **1354**. The compressive force in the springs **1362A** and **1362B** decreases as the springs expand. The controller **140** or a controller in the motor **112** is operatively connected to the pressure sensors and compares the measured pressure levels from the pressure sensors to a predetermined pressure threshold (block **1328**). Once the pressure sensors in the mounts **1366A** and **1366B** measure that the compressive force of the springs **1362A** and **1362B** has dropped below a predetermined threshold, the controller **140** generates an output signal via the user interface **110** to indicate that the brushes should be replaced (block **1332**). In some configurations, the controller **140** also disables operation of the saw **100** until any worn brushes have been replaced and the controller **140** performs the process **1320** again to confirm that the new brushes are no longer worn.

As described above, during operation the object detection system **102** receives sensing signals through a single sensing cable, such as the coaxial cable **720** depicted in FIG. **8B**, that includes two different conductors. Within a high vibration



31

environment such as the saw **100**, the sensing cable **720** may experience wear and faults over time that eventually require cable replacement during saw maintenance. If the sensing cable **720** breaks or is disconnected from any of the PCB of the object detection system **102**, the plate **120**, or implement enclosure **118**, then the PCB does not detect any sensing signal and can disable the saw **100** until the single sensing cable **720** is repaired. However, in some circumstances the sensing cable **720** experiences a “soft fault” in which the cable is not completely disconnected, but the cable continues to operate with greatly degraded performance in the saw. The PCB **102** still receives the sensing signal, but the fault within the sensing cable **720** introduces noise or attenuates the sensing signal, which reduces the accuracy of the object detection system **102**. FIG. **14** depicts a process **1400** for diagnosing soft faults in the sensing cable **720**. In the description below, a reference to the process **1400** performing an action or function refers to the operation of a controller, such as the controller **140** in the saw **100**, to execute stored program instructions to perform the function or action in conjunction with other components in the saw **100**.

Process **1400** begins as the object detection system **102** generates a predetermined excitation signal during a diagnostic mode (block **1404**). In one embodiment, the controller **140** activates the clock source **144** to generate the same sinusoidal sensing signal that is used during operation of the saw **100** using amplitude modulation. In another embodiment, the clock source **144** produces an impulse train including a series of delta pulses at a predetermined frequency to enable the controller **140** to receive an output corresponding to the unit impulse response of through the sensing cable **720** and capacitor **124**. In further embodiments, the clock source **144** generates any suitable predetermined signal that enables diagnosis of potential faults within the sensing cable **720**. During the diagnostic mode, the motor **112** in the saw **100** is deactivated and there is minimal electrical noise present within the saw.

Process **1400** continues as the controller **140** identifies a signal to noise ratio (SNR) of the detected excitation signal (block **1408**). In the saw **100**, the controller **140** detects a return signal in response to the excitation signal from the clock source **144** and the amplifier **146** that passes through the sensing cable **720** and the plate **120** and saw blade **108** of the capacitor **124**. Since the clock source **144** and driving amplifier **146** generate the excitation signal with a predetermined amplitude and modulation, the controller **140** identifies the SNR using a predetermined measurement technique that is otherwise known to the art. Of course, even in a an otherwise deactivated saw the excitation signal experiences some degree of attenuation through the sensing cable **720** and capacitor **124**, and some degree of noise, such as Johnson-Nyquist noise, is always present within the sensing circuit. As used in the context of the process **1400**, a measurement of SNR also includes a measurement of signal strength attenuation that does not include a direct measurement of noise. For example, the predetermined excitation signal is generated with a predetermined amplitude and the controller **140** measures the amplitude of the return signal. Some level of attenuation in the return signal is expected and a predetermined amplitude level for the signal strength of the return signal for a properly functioning sensing cable is identified empirically and stored in the memory **142**. However, if the amplitude of the return signal drops below a predetermined level, then the controller **140** identifies a potential fault in sensing cable **720**.

32

In an alternative configuration, the sensing cable **720** includes a third conductor that is electrically isolated from the first conductor and second conductor in the sensing cable. In one embodiment, the third conductor is formed as part of a second twisted pair in the sensing cable **720**, while in another embodiment the sensing cable includes two coaxial elements that form three separate conductors. One end of the third conductor is connected to the plate **120** in a similar manner to the first conductor as depict in FIG. **8C**. The other end of the third conductor is connected to an analog to digital converter (ADC) that is mounted to the PCB of the object detection system to provide a digitized version of the sensing signal to the controller **140**. During the process **1400**, the controller **140** measures a return signal based on the excitation signal through the third conductor instead of through the first conductor and the second conductor.

The controller **140** identifies if the measured SNR for the excitation signal drops below a predetermined minimum SNR ratio that is suitable for operation of the object detection system **102** (block **1412**). A fault in the sensing cable **720** attenuates the level of the received signal, introduces additional noise into the sensing cable **720**, or produces both an attenuation of signal strength and increase in noise that degrades the SNR. If the SNR remains above the predetermined threshold, then the sensing cable **720** is considered functional and the saw **100** continues with operation (block **1416**). However, if the measured SNR falls below the predetermined threshold, then the controller **140** generates an output indicating a potential fault in the sensing cable (block **1420**). In the saw **100**, the controller **140** generates the output via the user interface **110** to alert an operator to a potential cable fault. In some configurations, the controller **140** disables operation of the saw **100** until the sensing cable **720** is repaired or replaced.

It will be appreciated that variants of the above-described and other features and functions, or alternatives thereof, may be desirably combined into many other different systems, applications or methods. Various presently unforeseen or unanticipated alternatives, modifications, variations or improvements may be subsequently made by those skilled in the art that are also intended to be encompassed by the following claims.

What is claimed:

1. A method for monitoring brush wear in a motor of a saw comprising:
  - generating, with a sensor connected to a brush in a motor of the saw, a first signal corresponding to a level of wear in the brush, the generating of the first signal further comprising:
    - generating, with a current source in the motor, an electrical signal that passes through the brush; and
    - identifying, with a controller, a level of electrical resistance through the brush with reference to the first signal from the sensor;
  - identifying, with the controller, a level of wear for the brush with reference to the first signal, the identifying of the level of wear for the brush further comprising:
    - identifying, with the controller, that the level of wear in the brush exceeds a predetermined threshold in response to the level of electrical resistance being below a predetermined threshold; and
  - generating, with the controller and a user interface device, an output requesting replacement of the brush in response to the identified level of wear exceeding the predetermined threshold.



33

2. The method of claim 1, the generating of the first signal further comprising:

generating with the sensor the first signal corresponding to at least one of a level of electrical current or voltage in the brush.

3. The method of claim 1 further comprising:

disabling, with the controller, operation of the motor in response to the identified level of wear exceeding the predetermined threshold.

4. The method of claim 1 wherein the sensor generates the first signal during a diagnostic mode in which the motor is deactivated.

5. A system for measuring brush wear of a motor in a saw comprising:

a motor in a saw;

a brush in the motor;

a sensor in the motor, the sensor being configured to generate a first signal corresponding to a level of wear in the brush, the sensor further comprising:

a current source in the motor configured to generate an electrical signal that passes through the brush; and

the sensor being further configured to:

generate the first signal corresponding to at least one of a level of electrical current or voltage based on the electrical signal that passes through the brush;

a user interface device; and

a controller operatively connected to the motor, the sensor, and the user interface device, the controller being configured to:

receive the first signal from the sensor;

identify a level of electrical resistance through the brush with reference to the first signal from the sensor;

identify that the level of wear for the brush exceeds a predetermined threshold in response to the level of electrical resistance being below a predetermined threshold; and

34

operate the user interface device to generate an output requesting replacement of the brush in response to the identified level of wear exceeding the predetermined threshold.

6. The system of claim 5, the controller being further configured to:

disable operation of the motor in response to the identified level of wear exceeding the predetermined threshold.

7. The system of claim 5 wherein the sensor generates the first signal during a diagnostic mode in which the motor is deactivated.

8. A method for operation of a saw with an implement reaction mechanism comprising:

detecting, with an object detection system in the saw, contact between an object other than a work piece and an implement in the saw during operation of the saw; activating, with the object detection system, the implement reaction mechanism in the saw;

incrementing, with a controller in the object detection system, a counter in a memory corresponding to a number of times that the implement reaction mechanism has been activated; and

disabling, with the controller, operation of the saw in response to the counter exceeding a predetermined threshold.

9. The method of claim 8 further comprising:

resetting, with an external programming device, the counter in the memory during a maintenance operation; and enabling, with the controller, operation of the saw in response to the counter being reset.

10. The method of claim 8 further comprising:

generating, with a user interface device, an output indicating that the saw is disabled and requires service in response to the counter exceeding the predetermined threshold.

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